XVI. NEUROPHYSIOLOGY

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A. A NEW CLASS OF PRECISION MECHANISMS FOR OPTICAL RESEARCH

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1. Introduction

In the course of perfecting a new type of x-y filar micrometer, we have come upon a form of construction for precision mechanisms that is adaptable in a wide range of applications. In particular, we have designed two forms of microscope measuring stage, a precision variable hexagonal aperture, several adjustable slit mechanisms, and an angular interpolating turntable with a potential of arc-second accuracy. In all of these designs we utilize a compact form of construction in which various plates, driven by micrometer screws and separated by steel balls running in linear or curvilinear V-grooves, are sandwiched together to form a precision mechanical assembly.

2. Precision x-y Filar Micrometer

A filar micrometer is a measuring instrument that operates in the focal plane of the eyepiece of a compound microscope. For applications to printed circuits, and perhaps to cell biology, it is useful to be able to measure simultaneously in both x and y coordinates. Figure XVI-1 shows a model that illustrates the mechanical principle of our new form of x-y movement. The device is symmetric in x and y coordinates, the x-y coordinate system of the moving stage is at 45° to the parallel axes of the stationary micrometers, and the motion generated by each micrometer screw, in effect, is geared down by a factor of $\sqrt{2}:1$. In this crude form, the device performs very poorly, since it is not possible to find low friction materials that will maintain the required mechanical accuracy. For a second model we used flanged miniature ball bearings, running in milled slots. This model performed quite accurately, but in its fabrication an excessive amount of precision machining was required.
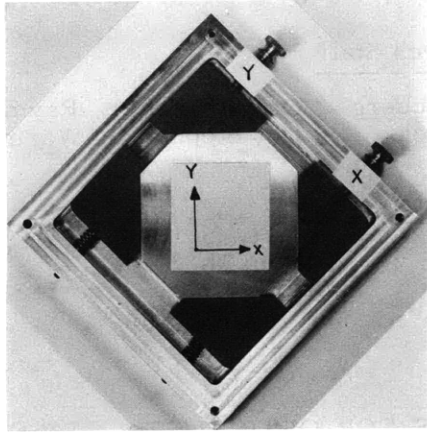
Fig. XVI-1.

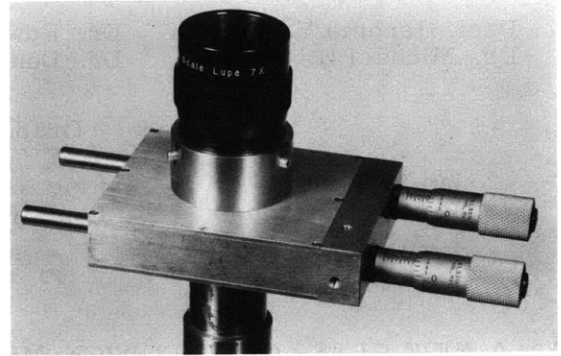Model illustrating the principle of the new x-y stage in the filar micrometer.

Fig. XVI-2.

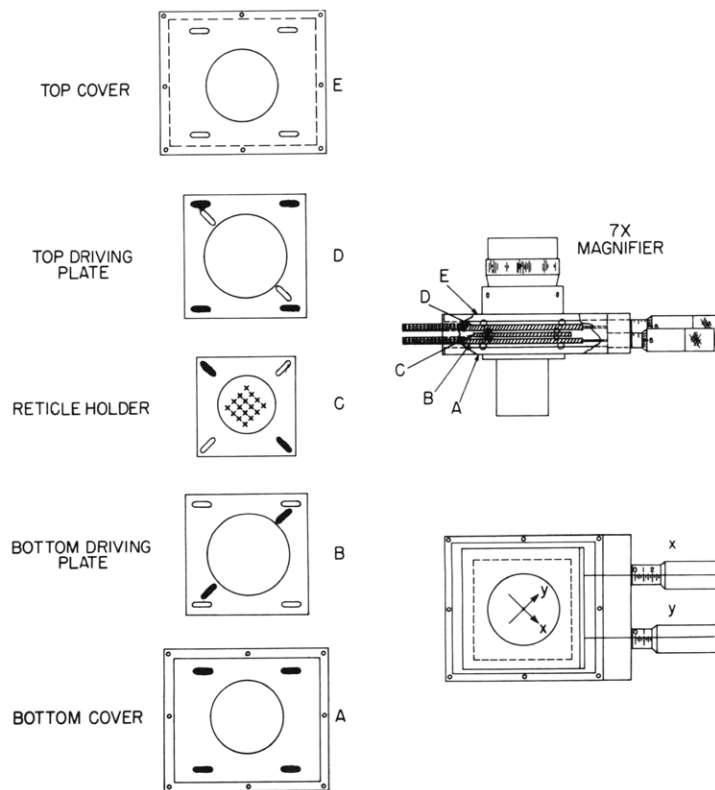Prototype model of the new x-y filar micrometer.

Fig. XVI-3. Parts and assembly of the new filar micrometer. Five machined plates, separated by balls running in linear V-grooves form the sandwich construction. Solid and open lines indicate V-races on the top and bottom plate surfaces.

Figure XVI-2 is a photograph of our third model, in which we used the new sandwich construction. Figure XVI-3 shows in detail the arrangement of the five sandwich plates that form the assembly, and the grooves and slits in each of the individual plates. The two cover plates are stationary, and have V-grooves milled parallel to the micrometer axes. The adjacent pairs of inner plates are driven by separate micrometer screws that have narrow shafts and hemispherical end tips staggered in the vertical plane. The innermost plate, which holds the reticle (a glass plate with precision fiducial marks), is supported at opposite corners by pairs of balls running in V-grooves at 45° to the parallel axes of the micrometers and engaging similarly oriented V-races in the adjacent plates. The reticle is a rectangular array of fine optical crosses, spaced exactly 0.0707" apart along each of the 45° diagonals. Thus four turns of either micrometer screw (0.100" motion) translates the measuring array of the reticle into itself.

To locate any object in the field of view of the eyepiece and reticle, it is only necessary to move each micrometer screw by an amount that is never more than four turns, thereby positioning one of the set of numbered crosses over the target. The measured accuracy in this model of the device is 0.0002", corresponding to a perceived error of 0.0014" with a 7X magnifier, or approximately 0.5 arc min at a conventional viewing distance. We judge this to be satisfactory. Furthermore, tests with a measuring microscope indicate that there is less than 0.0001" coupling between the axes of this device.

The new filar micrometer using sandwich construction has many advantages: (a) the device is symmetrical in x and y motions, (b) neither micrometer moves relative to the observer, (c) there is a significant gearing down of the motion of the micrometer screws, (d) the device utilizes rolling contact in all moving elements save for the micrometer screw, and hence friction, stiction, and hysteresis errors are minimal and the mechanism proper can operate without lubrication, and (e) the fabrication difficulties for the separate elements are less than those in an x-y stage of conventional design and comparable precision.

3. Precision x-y Measuring Microscope Stage

Figure XVI-4 shows a precision measuring microscope stage, similar in design to the filar micrometer. The nonintegral $1/\sqrt{2}$ ratio by which the stage operates necessitates the use of special pitch micrometer screws such as are used in certain precision tooling. In this application, the sandwich construction has the following advantages: (a) low profile, (b) large optical aperture, (c) ease of adaptability to electronic readout or drive, since both micrometers are stationary, (d) low inertial effects, since all moving parts are lightweight (i.e., the stage need not be clamped when the microscope is transported), and (e) ease of sealing the entire mechanism against intrusion of dirt
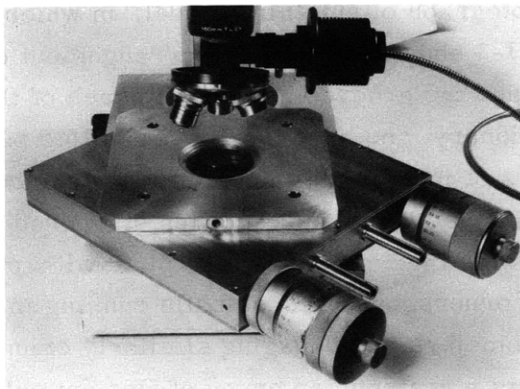
Fig. XVI-4.   Prototype model of a measuring microscope stage utilizing the new sandwich construction. Special micrometer screws with $\sqrt{2}$ times normal pitch ratios would be used in production instruments.

and abrasives.   The disadvantages include a need for special pitch micrometer screws, and the limited range of travel of the measuring stage, which is 0.7" in each direction.

4.   Precision Geared-Down Microscope Stage

The element limiting the accuracy of a measuring microscope of conventional design is the micrometer screw, which rarely exceeds 0.0001" (or 2 μm in a metric microm- eter) least count.   The resolution of an ordinary 20X microscope objective is 0.5 μm, and the repeatability of settings is generally better.   Thus we may contemplate the advan- tages of an x-y micrometer stage in which the motion of each of the micrometer screws is "geared down" by an additional factor of, say, 5:1 or 10:1. Such a design can easily be realized with sandwich construction, by using V-grooves inclined at precisely determined angles.   Such a stage would be useful in very accurate measurements over a moderate- sized field, as in a semiconducting chip.   The advantage of such a direct measurement stage over the filar micrometer is that errors arising from uncertainties in the magni- fication of the microscope become irrelevant.

It has been pointed out that the sandwich construction that we have described can be utilized in a more conventional way to construct an x-y stage in which the micrometers are mounted at right angles, and the stage moves in 1:1 ratio with the micrometer screws.   Such a construction has already been anticipated.[1]

5.   Precision Variable Hexagonal Aperture

The versatility of sandwich construction is further illustrated in Fig. XVI-5a where we show a novel form of variable hexagonal aperture, and in Fig. XVI-5b which shows
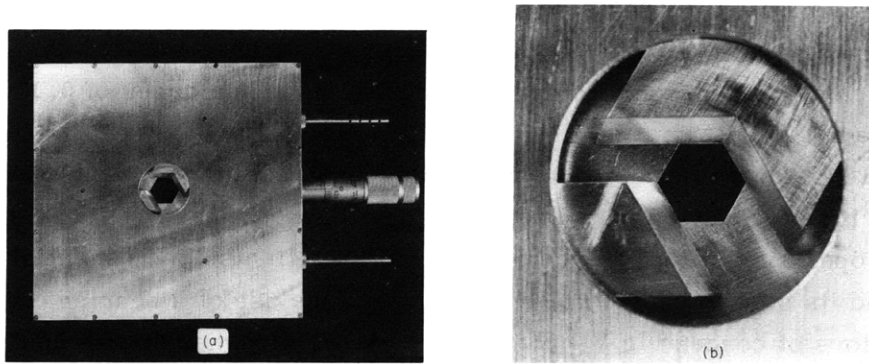
Fig. XVI-5.　(a) Overview of the variable hexagonal aperture assembly. The micrometer screw drives an intermediate plate, which in turn, by means of balls running in appropriately oriented V-grooves, drives each of the blade assemblies symmetrically.
(b) Enlarged view showing the arrangement of the three moving blades. The key element of the assembly is the hermaphroditic blade moving in from the left.

the somewhat unusual arrangement of the three converging blades, at least one of which must be hermaphroditic (i. e. , composed of two opposing elements). It will also operate with three hermaphroditic blades. The device has four linearly moving parts, plus the micrometer screw, and requires 18 steel balls. The micrometer screw drives a secondary plate (not visible) that, by means of inclined ball races, drives the individual blades, thereby opening the aperture. The micrometer setting thus directly determines the radius of the circumscribing circle. With this design the maximum aperture size is 1. 1" and the minimum is less than 0. 005", which corresponds to a 220:1 range. Furthermore, the edges of the blades that define the hexagon are coplanar, and the centration of the hexagon is accurate to 0. 001" over the range of aperture sizes. This device is an extension of the well-known variable square aperture assemblies that are used extensively in optics and in biology in the form of a rat guillotine.

The variable hexagonal aperture is more accurate and has a larger range of adjustment than the conventional leaf aperture that is used in camera shutters, and the hexagonal opening more closely approximates a circle than does the equally accurate variable square aperture. It can be shown that the hexagon is the highest order polygon that can be so synthesized. Moreover, it need not be a regular hexagon; the angles and the drive ratios may be varied to effect an approximation to an ellipse, which may find use in anamorphic systems. Such an ellipticity adjustment can be appended to the present device, with the aid of a second micrometer and an additional drive plate.

6. Precision One-Degree Interpolating Turntable

A need exists for a simplified design of an angular turntable to provide interpolation

between the steps of the Ultradex.[2] Two forms of this ultraprecision angular indexing device exist: one steps in one-degree increments, the other, the 1440, steps in quarter-degree increments.[3] Each exhibits angular accuracies of the order of 0.1 arc second, or 0.5 microradian.

Figure XVI-6 is a photograph illustrating the construction of the interpolating turntable, which utilizes sandwich construction with both linear and circular concentric V-grooves. The operation of this device depends on two effects: the essential equivalence of the angle and its sine for angles less than 1°, and the use of a bearing formed by balls running in sectors of concentric V-grooves of large radii, whereby the center of rotation of the bearing is located considerably outside the physical boundary of the device. The effective lever arm by which linear motion is translated into angular rotation is the distance from the center of the coaxial V-grooves to the bearing axis of the turntable. Thus, for example, when using a metric micrometer, and an equivalent radius of 57.295 cm (~22.557"), each centimeter of travel corresponds to 1°, and the device reads directly in increments of 0.0002° (0.72 arc sec).
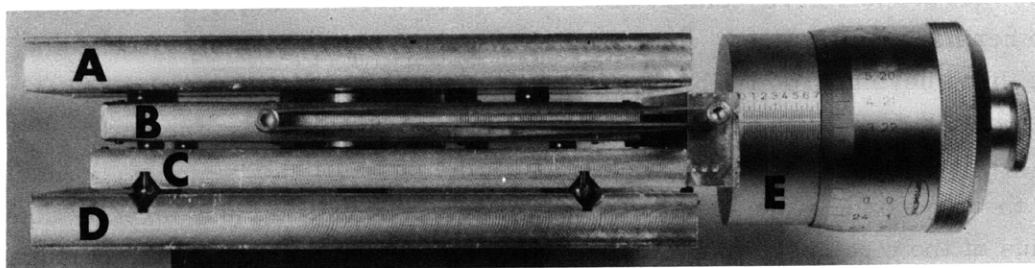

Fig. XVI-6. Construction of the plus and minus one-degree angular interpolating turntable. Plates A and B are separated by four balls, running in matched concentric V-grooves having approximately 15" and 19" radii. Plate pairs B and C, and C and D are separated by steel balls running in orthogonal sets of linear matched V-grooves. The angular rotation of the top plate is determined by the setting of the precision micrometer screw; each small division (0.0001") corresponds to 1.2 arc sec, and 1° equals 0.300".

We have determined that the performance of the crudely machined (student-made) model shown in Fig. XVI-6, which has a sensitivity of 1.2 arc sec per 0.0001" least division, is as follows: accuracy ±10 arc sec; repeatability of setting ±1.0 arc sec average; hysteresis (with reversal of micrometer motion) 1.5 arc seconds. In view of the known inaccuracies in machining this model, these data, especially the repeatability and hysteresis error, are encouraging. A second model made from hardened and ground steel is being fabricated. Consultations with machine tool experts indicate that the accuracy of this device is most likely to be limited by the accuracy of grinding and lapping

of the concentric V-grooves.

7. Summary

The sandwich construction described here, utilizing a multiplicity of parallel plates, driven by micrometer screws and constrained by balls running in linear or curvilinear V-grooves, can be used to form a variety of precision mechanisms that have applications in optics and mechanics. Several such devices have already been built and tested, and their performance has been generally satisfactory.

References

1. Naum G. Basin, Alexei V. Vysotsky, Anatoly P. Kurochkin, and Ura J. Okun, United States Patent Office 3,829,978. WORKTABLE FOR POSITIONING WORKPIECES IN MEASURING DEVICES TO CHECK DIMENSIONS. Patented August 20, 1974.

2. Registered Trade Mark, The A. A. Gage Company, Detroit, Michigan.

3. See Wayne K. Moore, "Foundations of Mechanical Accuracy," Moore Special Tool Company, Bridgeport, Connecticut, 1972.