AZIMUTH, ELEVATION ANGLE, AND AND ROLL[3,5]

$$M = \begin{bmatrix} -\cos\kappa & \sin\kappa & 0 \\ \sin\kappa & \cos\kappa & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & -\sin\omega & \cos\omega \\ 0 & \cos\omega & \sin\omega \end{bmatrix} \begin{bmatrix} \cos\alpha & -\sin\alpha & 0 \\ \sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$= [A_z(\kappa)][B_x(\omega)][C_z(\alpha)]$$

By rule (1) A_z must be clockwise if it is to be premultiplied, and by rules (1) and (3) B_x must be clockwise if it is to be postmultiplied. Hence,

$$Q_x = [C_z]^T[P_x][C_z] = \begin{bmatrix} 0 & 0 & \sin\alpha \\ 0 & 0 & \cos\alpha \\ -\sin\alpha & -\cos\alpha & 0 \end{bmatrix}$$

and

$$\frac{\partial M}{\partial \kappa} = [P_z][M] = \begin{bmatrix} m_{y'x} & m_{y'y} & m_{y'z} \\ -m_{x'x} & -m_{x'y} & -m_{x'z} \\ 0 & 0 & 0 \end{bmatrix}$$

$$\frac{\partial M}{\partial \omega} = [M][Q_x] = \begin{bmatrix} -m_{x'z}\sin\alpha & -m_{x'z}\cos\alpha & m_{x'x}\sin\alpha + m_{x'y}\cos\alpha \\ -m_{y'z}\sin\alpha & -m_{y'z}\cos\alpha & m_{y'x}\sin\alpha + m_{y'y}\cos\alpha \\ -m_{z'z}\sin\alpha & -m_{z'z}\cos\alpha & m_{z'x}\sin\alpha + m_{z'y}\cos\alpha \end{bmatrix}$$

$$\frac{\partial M}{\partial \alpha} = -[M][P_z] = \begin{bmatrix} m_{x'y} & -m_{x'x} & 0 \\ m_{y'y} & -m_{y'x} & 0 \\ m_{z'y} & -m_{z'x} & 0 \end{bmatrix}$$

*Electronic Space Rods for Large Plotters**

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ABSTRACT: *A servomechanism is described which automatically and continuously positions the illuminators for each of the projectors in a stereo plotter. The position of the plotting table is sensed by means of a lighting system located on the table platen which is monitored by photosensors associated with the illuminators. In this manner the optical axis of the illuminators is continuously directed onto the center portion of the plotting table platen for all movements of the table. Mechanical connections between the plotting table and the illuminators are thus replaced by the "space rods" of light emanating from the plotting table lights.*

SEVERAL mechanical systems have been used with direct projection plotters to couple illuminator movements to the motion of the tracing table. These mechanical couplings maintain the optic axes through the lamps, condensers, and projection lenses of the

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projectors aligned with the tracing table platen. The rods required between the projectors and the tracing table are generally an encumbrance to the operator and impede tracing table movement. "Electronic Space Rods" are an electro-optic solution which eliminate the mechanical rods by substituting an infrared guidance system.

Figure 1 shows a portion of a plotter including one projector and tracing table. Four infrared sources are located at 90° intervals around the periphery of the tracing table platen as shown. (Marked N, E, S and W). These sources are tracked by a servo system consisting of a sighting tube containing an infrared detector, an electronic amplifier and a pair of a.c. servo motors. The sighting tube is connected to the illuminator arm and its axis is nearly coincident with the optic axis of the projector. The two servo motors are arranged to drive the illuminator about two orthogonal axes to keep the optic axis of the projector centered on the tracing table platen. Several projectors can operate simultaneously in the above manner provided each has such a tracking system.

Four subminiature lamps are used on the tracing table platen as infrared sources. Infrared transmitting filters cover each of the lamps to eliminate distracting visible light. The lamps are supplied a one-half wave rectified 60 cps voltage which results in a strong 60 cps component in the output light intensities shown in Figure 2. The voltages supplied to the lamps compose a four-phase system. The lamps are identified as "North," "East," "South," and "West." The phases of the 60 cps components in their driving voltages are spaced at 90° intervals. It will be noticed from Figure 2, that a thermal lag exists in the light intensity decay but this is of minor importance because adequate 60 cps content remains in the light output.

The sighting tube consists of a pair of lenses. The first lens forms an image of the tracing table platen on the second lens. The second lens forms an image of the first lens on a lead sulphide photodetector. An infrared filter is also included in the tube to reduce the effect of ambient light. When the tube axis is centered on the tracing table platen as in Figure 2, each lamp contributes an equal amount to the flux incident on the photodetector. The result is a signal whose fundamental is at 240 cps as can be seen by adding the four light intensities shown in Figure 2. Such a signal produces no torque when converted from light intensity to voltage and when applied to the 60 cps servo motors.

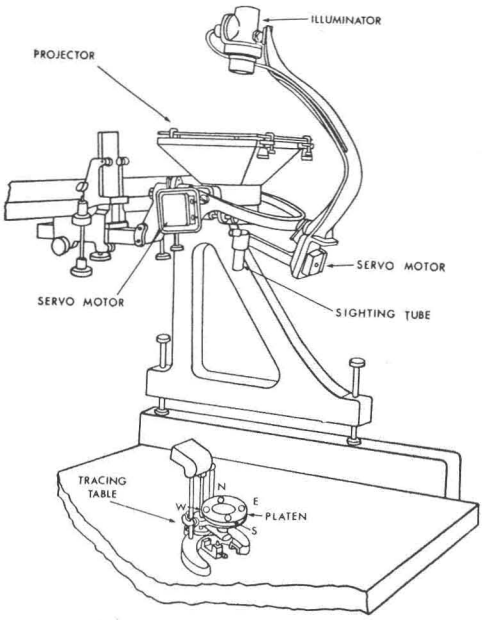

FIG. 1

If, as in Figure 3, the sighting tube axis is pointed "North" of the center of the tracing table platen, the lamps will not make equal contributions to the light flux incident on the photodetector. In the case shown, the North lamp contributes more than the South, while the East and West contribute equally. The combination of the East and West light flux in Figure 3 is a signal whose fundamental is at 120 cps and, therefore, no torque is produced in the servo motor associated with the "East–West" motion of the projector illuminator. The combination of the "North" and "South" signals, however, does contain a 60 cps component which does result in torque from the "North–South" motor. The system is arranged so the resulting rotation of the motor is in a direction to restore the sighting tube axis to the center of the tracing table platen. Displacement of this axis in any other direction is corrected in a similar manner.

A means of obtaining the necessary driving voltages for the lamps is shown in Figure 4. The circuit consisting of the center-tapped transformer secondary, using a resistor and capacitor, is a well known method for obtaining two sinusoidal voltage waveforms phased at 90°. The rectifiers are necessary to produce 60 cps modulation of the light intensity rather than 120 cps which exists when 60 cps a.c. is applied directly to a lamp filament.

Figure 4 also shows the arrangement of the electrical portion of the system. Two projec-

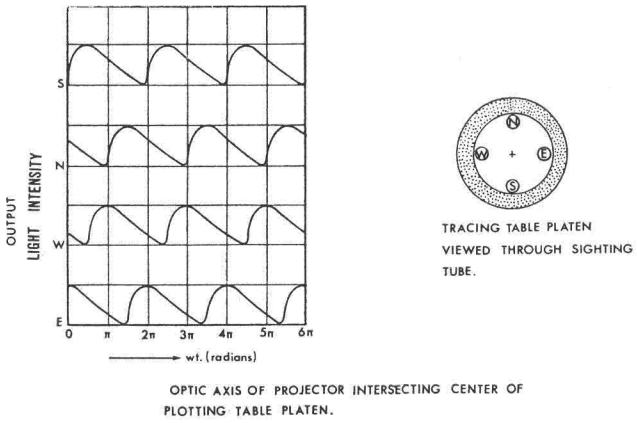

FIG. 2

tors are shown but more or fewer could be used. The light incident on the photodetectors causes a change in their resistance which is approximately proportional to the light intensity. These resistance changes are converted to voltage changes and are amplified. The output current from the amplifiers can be considered as being proportional to the sum of the light fluxes incident on the photodetectors from each of the four lamps on the tracing table platen. In general, contributions from all four phases of 60 cps are present in the amplifier current outputs. Capacitors are therefore placed in series with the signal windings of the "East–West" (E–W) servo motors to advance the phase of the current to these motors by 90°. The main field windings of all servo motors are connected in parallel across the 60 cps supply. Two-phase servo motors produce no torque unless the signal field current contains a component at 90° with respect to the main field current. The 60 cps fundamental component in the North lamp light intensity produces torque in the N–S motors in a direction to move the projector and sighting tube axes South on the tracing table platen. This signal produces no torque in the E–W motors because the signal producing torque in the N–S motors is shifted 90° by the capacitors in series with the E–W motor control fields. Control field currents resulting from East or West lamp light flux will produce torque in the E–W motors because these light fluxes are shifted 90° with respect to the North and South lamp fluxes.

Several additional refinements have been included in the system. Velocity-proportional 60 cps signals are obtained from the motor shafts and are fed back to appropriate points in the amplifiers. This results in near-optimum damping characteristics for the system, together with rapid response. Phase and gain adjustments have been omitted from this discussion, but are of course included in the

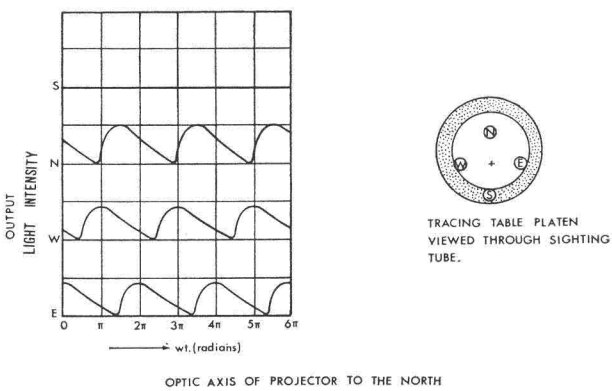

FIG. 3

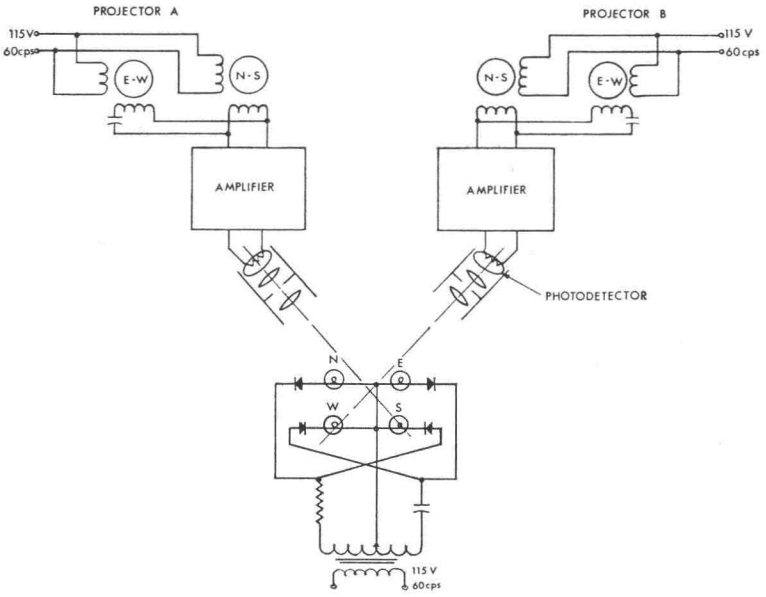

FIG. 4.

actual system. Generally it has been found that little if any adjustment has been required after the initial alignment.

In operation, two projectors are generally used. Each is equipped with its own tracking system. The system has no trouble following normal movements of the tracking table. If the projector axes completely miss the plotting table, the projectors stand still or drift very slowly. If the operator's hand intercepts the beam from one lamp, the projectors are so driven that their axes move in the direction of the occluded lamp. When the obstruction is removed, normal tracking is quickly reestablished.

An interesting result is obtained when the plotting table platen is rotated severely. Normally the two servo drives are uncoupled because the motor drives are orthogonal and aligned with the plotting table axes. When the table platen is rotated away from its normal orientation the correcting motion of one motor causes an output torque from the other motor. The result can be a continuous circular orbit of the projectors (in the case of a 90° displacement). In normal operation this effect is not encountered, since minor angular motions of the table result in an unnoticeable spiral closure.

The electronic space rods have been tested over a considerable period. To date no serious problems have been encountered. The system has proved to be reliable and simple to use. It is expected that widespread application will be made in stereo plotters.

REFERENCES

"Photogrammetric Projection Apparatus." U. S. Patent 02901941—C. H. Brumley, September 1, 1959.

CORRECTIONS TO 1963 YEARBOOK

Page 395 Insert Dr. Wm. P. Tayman as Chairman of American Standards Association

Page 418 Geomorphic Associates—Change Calif. to Okla.

Page 511 Dr. Samuel W. Levine—Change business occupation to Fairchild Camera & Instrument Corp., Technical Assistant to Chairman of the Board