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SHC-66-8445-37

FINAL REPORT

Gamma 1 Rectifying Printers

January - 1966

NRO review(s) completed.

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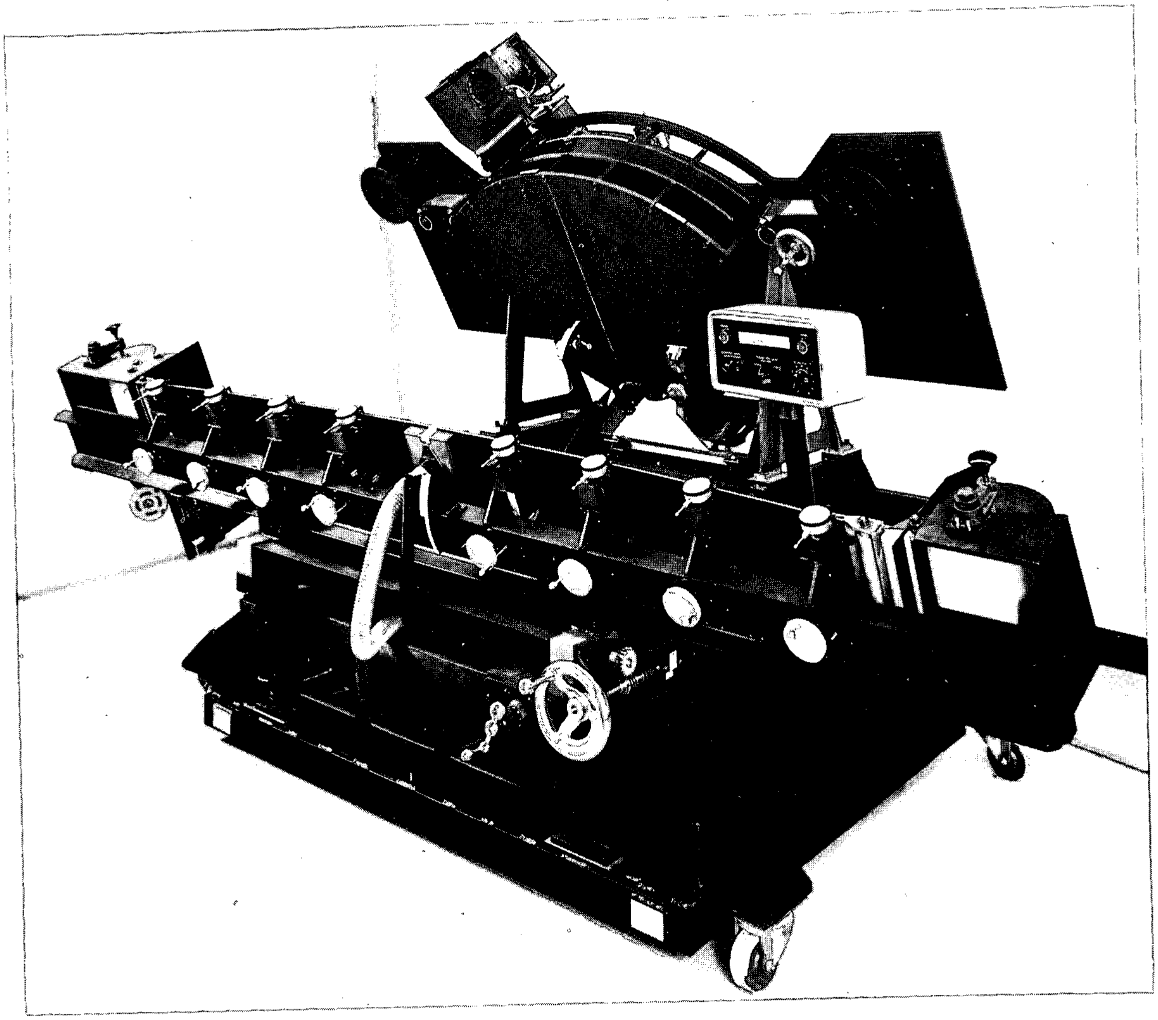

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Gamma I Rectifying Printer

CONTENTS

FIGURES

25X1

TABLES

1. SCOPE OF THIS REPORT

This report has been prepared to: (1) describe the Gamma I instrument, (2) give an explanation of the theoretical considerations that led to the final design, (3) generalize the salient features of the contract, (4) define the conclusions and recommendations formulated as a result of contract performance, and (5) serve as a guide for diagnosing resolution and geometric irregularities of the subsequent realignment of the instrument.

2. PURPOSE OF THIS CONTRACT

The purpose of this contract was to design, fabricate, test, and put into operation, two Gamma I Printers capable of rectifying the inherent distortions of photographic imagery acquired by a specific type of panoramic camera of defined focal length.

The design of these instruments was controlled and governed by Design Specification, Gamma I Printer, 10 April 1963.

The award of the contract was based on Design Study, Gamma I and II Printers, 17 August 1962, subsequently modified by the aforementioned design specification.

The design phase of the contract was initiated in April 1963, and culminated in the delivery of two instruments to the contractually specified installation site in May and June 1965.

In February 1965 the contract was renegotiated to include a phase for the preparation of a test plan entitled "Engineering Test Plan for Gamma I Rectifying Printer." The publication was submitted for approval on 18 January 1965 and was approved and accepted in February 1965.

3. CONCLUSIONS

As a result of delivering two Gamma I Rectifying Printers under this contract, the following conclusions have been reached:

The average resolution obtained over the primary tilt range of 10 to 20 degrees exceeds the values specified in the design specifications for minimum, mean, and maximum altitudes. Within these ranges, it has been noted that occasionally and randomly the resolution falls below the 50 lines per millimeter minimum allowable level. Because these occurrences are random it is difficult to isolate the exact cause; however, it could be due to any of the following reasons or combinations thereof: (1) improper negative position due to film buckle, foreign substance, or film motion; (2) inconsistent instantaneous exposure due to sweep arm chatter; (3) foreign matter on the focus cam surface, or any of the associated mechanisms; (4) foreign matter on lens external elements; or (5) external transient vibrations. Nonrepeating resolution degradation over isolated areas due to the above conditions should be accepted as such, and should not hinder the general operation of the equipment.

The average resolution obtained over the secondary tilt range of −5 to +10 degrees is generally lower and more inconsistent than that obtained over the primary ranges. The overall level of resolution over these ranges can be increased, if so desired, by adjusting the printer (with the possibility of new cam calibration) to obtain optimum focus at the desired conditions.

The accuracy of geometric reproduction meets the specified requirements over those ranges measured during equipment acceptance. Geometric fidelity is interdependent on numerous external inaccuracies, such as film stretch during processing, measuring equipment inaccuracies, and theoretical displacement assumptions. These external inaccuracies make any statement of equipment accuracy debatable. However, it has been shown that when these conditions are properly accounted for, the rectifier's accuracy falls within the specified limits.

Thorough and explicit techniques for geometric accuracy determination and extensive testing must be performed to determine, with confidence, the degree of geometric fidelity.

The maintenance of the equipment is straightforward and there is no component that cannot be replaced within 2 hours by a trained technician. All components were originally selected for high reliability during extended service life.

The principle of operation is simple, and no extended, special, or unique operator training program is needed.

The production rate of this printer is relatively high for an instrument of this kind.

4. RECOMMENDATIONS

The following general recommendations are provided as aids in the development of future rectification equipment. These recommendations, which are of a technical nature, have been formulated as a result of experience gained during the performance of this contract, and if adopted, should enhance the performance of subsequent equipment.

1. The roll indicator mechanism should be redesigned as follows to facilitate the setting of nadir offset:
   - The scale should have very fine engraved markings for observation.
   - The witness line should be finer on the plastic slide.
   - The observation of the settings should be facilitated by adequate illumination and magnification.
2. An investigation should be instituted into utilizing glass instead of metal for the film support rails for the following reasons:
   - To reduce the possibility of film damage by the edges of the metal rails during transport
   - To allow the projection of the complete format and all auxiliary information located on the film margins.
3. The slit width control should be redesigned to facilitate the setting of the slit during operation. A scale should be attached for obtaining repeatability of settings.
4. The condenser system should have quick-release fasteners, rather than screws, to facilitate optical alignment if the need arises.
5. The mechanical advantage of the glow plate should be changed to reduce the possibility of jarring the plate during operation.
6. The location of the handwheel for the 70-millimeter film transport should be changed to facilitate operation by short operators.
7. The scale on the conjugate slide collar should be changed to read in the opposite direction to reduce the possibility of operator error in setting.
8. The lens focus cam should be relocated to the rear of the instrument for greater accessibility and to reduce calibration error. The sensitivity of the focus cam should be reduced by altering the overall drive ratio.
9. The vacuum supply system should be located outside of the darkroom to reduce noise, and consequently, operator fatigue.
10. A calibrated length mark should be exposed onto the output film at the easel to facilitate determination of nadir setting error and film deformation during processing.

11. The scan time scale on the control panel should be changed to read directly in seconds of total scan.
12. The scan arm drive roller carriage should be altered so that the roller may be lifted from the drive track and returned to it with constant contact force.
13. An investigation into a different type of light source should be made so as to provide greater illumination with less heat.
14. The casters should be provided with positive locking devices.
15. Film cassettes should be provided on the supply and takeup sides of the output film to prevent fogging of film by accidental illumination. The cassettes will also facilitate the testing of the printer.

5. GEOMETRIC CONSIDERATIONS

The Gamma I instrument utilizes the technique of proportional duplication to remove the inherent distortions of panoramic photography; i.e., during the printing operation, the film plane, the optical conjugates, the object area configuration and scale, and the exposure intensity variations are specified multiples of their counterparts in the actual taking case.

Although rectifying printers using the proportional duplication technique have been built in the past and are currently operating in a satisfactory manner, they were designed to operate on vertical photography made at a single altitude (or within such a narrow range of altitudes that the variation did not significantly affect the transformation process).

Because the Gamma I specifications required that the instrument accommodate imagery taken in the oblique manner through a fairly wide range of tilt angles, and because the allowable camera altitude range is quite broad, it was required that the mechanical and optical design of this instrument be much more sophisticated than that for an instrument to accommodate vertical, single altitude panoramic photography. This sophistication of design necessitated an involved analysis of the physical aspects of the concept and the development of unique mechanisms, components, and techniques.

5.1 PANORAMIC DISTORTIONS

The following five types of distortion are inherent in tipped panoramic photography:

1. Panoramic distortion is the displacement of images from their true, or expected, orthographic position due to the geometry of the focal plane and the scanning action of the lens.

2. Scan positional distortion is the displacement of images from their true, or expected, geometric position due to the forward displacement of the vehicle during the scan period of the lens. This distortion is in addition to, and modifies, the position of points due to panoramic distortion.

3. IMC distortion is the displacement of images from their true, or expected, geometric position due to lens motion which is used to compensate for image motion during the exposure period. This distortion is in addition to, and modifies, the position of points due to both panoramic and scan positional distortion.

4. Convergent tip distortion is the displacement of images from their true, or expected, geometric position due to the introduction of a tipped optical axis in the line of flight. This distortion is in addition to, and modifies, the position of points due to panoramic, scan positional, and IMC distortion.

5. Roll distortion is the displacement of images from their true, or expected, geometric position due to roll of the camera about an axis parallel to the line of flight. This distortion is in addition to, and modifies, the position of points due to the other distortions.

In the Gamma I instrument, panoramic, convergent tip, and roll distortions are removed during the printing operation. Scan positional and IMC distortions (which appear as a residual centerline curvature that is the algebraic sum of the two) are not considered, since the V/H ratio of the taking system is such that these distortions are not of sufficient magnitude to significantly affect the results.

5.2 OBJECT SPACE CONSIDERATION

Fig. 5-1 illustrates the object space geometry. The camera at altitude, H, above the mean earth radius, R, has a tip angle, t. The camera axis intersects the sphere at point B in the line of flight, forming the arc AB. This arc intercepts the angle, δ, at the earth's center, o. A plane, E, tangent to the sphere at point B approximates the earth's curvature in the line of flight. It becomes necessary to consider a new tip angle, t′. If

$$\sin(t + \delta) = \sin t' = \frac{R + H}{R} \sin t$$

then

$$\delta = t' - t$$

Our total object distance, D_O, is then

$$D_O = \frac{H \cos(\delta/2)}{\cos(t - \delta/2)}$$

The initial tip reference, H, is replaced by H′

$$H' = D_O \cos t'$$

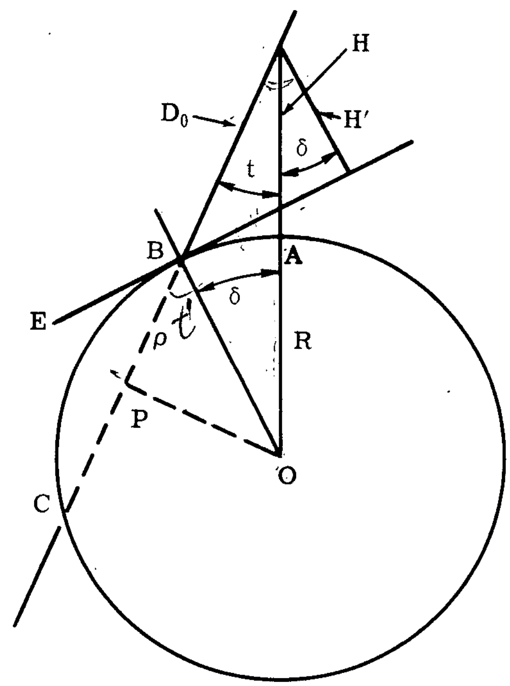


Fig. 5-1 — Object space geometry, $R = 20.9 \times 10^6$ feet (the radius of a sphere having the same volume as the earth)

If we then consider D_O to be lying in the scanning plane, this plane would cut the sphere in a circle whose circumference should contain points B and C. The circle with radius PB would necessarily contain the scan centerline on the surface of the sphere. This radius, PB or ρ is equal to R cos t′.

5.3 IMAGE SPACE CONSIDERATIONS

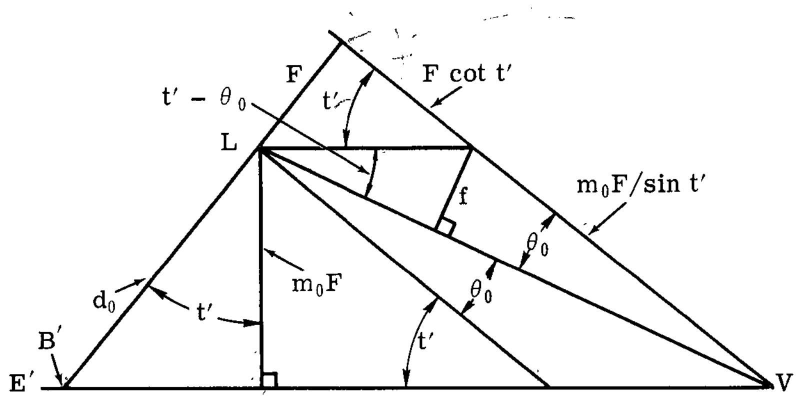
With the central isometric magnification given as a starting parameter, we can derive the principal plane rectifier dimensions. From Fig. 5-2,

$$d_0 = \frac{m_0 F}{\cos t'}$$

$$\tan \theta_0 = \frac{F}{F\left(\cos t' + \dfrac{m_0}{\sin t'}\right)} = \frac{\sin t'}{\cos t' + m_0}$$

and

$$f = \frac{m_0 F}{\sin t'} \sin \theta_0$$



M_0	central isometric magnification
F	camera focal length or rectifier lens to film distance
d_0	lens to rectifier easel distance
t'	rectification tip angle
E'	easel plane
f	rectifier lens focal length
θ_0	rectifier lens tip for any easel tip t' satisfying the Scheimpflug condition
V	rectifier vanishing point

Fig. 5-2 — Rectification geometry

It should be apparent that for any new tip angle, t′, the focal length changes. This creates problems for a finite conjugate, high resolution lens; instead, a fixed optimum focal length was selected and the above dimensions were calculated with the given value of f. Then

$$\sin (t' - \theta_0) = \frac{f}{F} \sin t'$$

$$m_0 = \frac{\sin (t' - \theta_0)}{\sin \theta_0} = \frac{\cos t'}{(F/f) \cos \theta - 1}$$

and

$$d_0 = \frac{m_0 F}{\cos t'}$$

We have now provided a basis for scale determinations in the principal plane of the rectifier (see Fig. 5-3). The map scale, M, is

$$M = \frac{d_0}{D_0} \quad \text{or} \quad 1 : \frac{D_0}{d_0}$$

The easel radius of curvature, R′, is

$$R' = RM$$

The map scale, ρ′, is

$$\rho' = \rho M = R' \cos t'$$

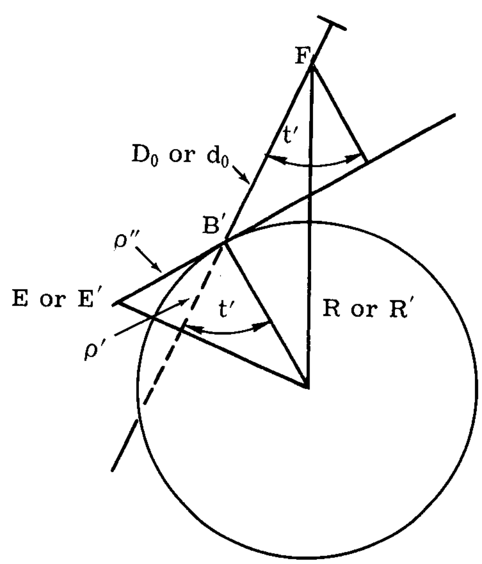


Fig. 5-3 — Object image comparison

It is apparent that for changes in easel tip, t′, d_0 varies accordingly, therefore changing the map scale, M.

5.4 RECTIFIER FILM TO EASEL TRANSFORMATION

Fig. 5-4 illustrates the film to easel transformation relationships.

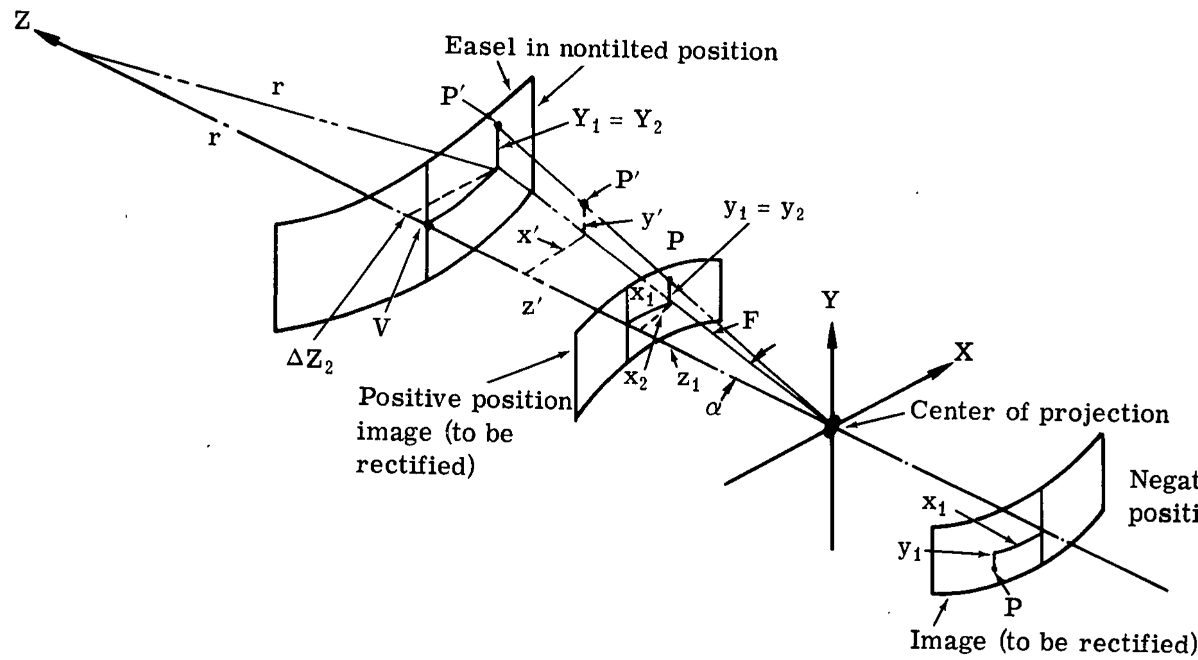


Fig. 5-4 — Film to easel transformation

A point, P, in the image is defined by two coordinates, x_1 and y_1, measured in the developed image surface. In a cartesian coordinate system through the lens (center of projection), shown in Fig. 5-4, the same point, P, is described by a set of coordinates (x_2, y_2, z_2) shown by the broken lines.

From Fig. 5-4

$$\alpha = \frac{x_1}{F}$$

$$x_2 = F \sin \alpha = F \sin \frac{x_1}{F}$$

$$y_2 = y_1$$

$$z_2 = F \cos \alpha = F \cos \left(\frac{x_1}{F}\right)$$

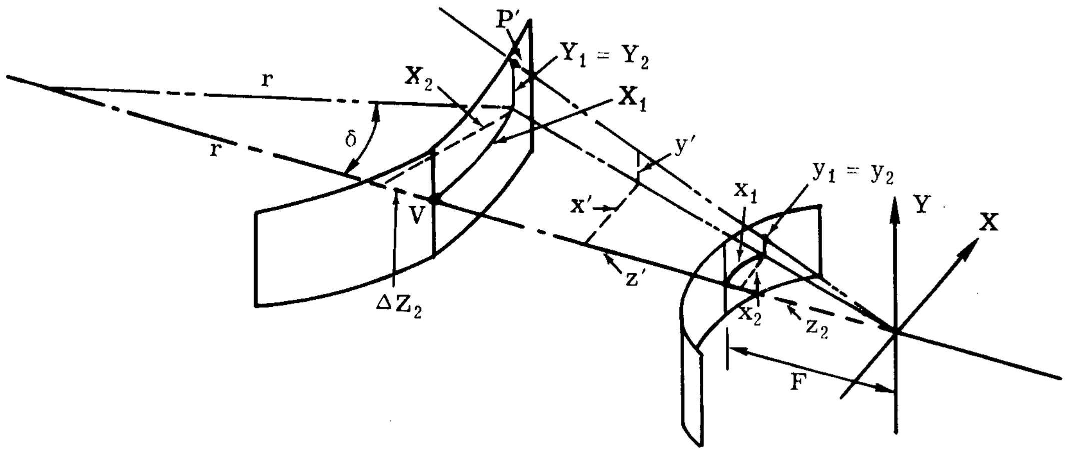


Fig. 5-5 — Geometry before tilt

From Fig. 5-5

$$\delta = \frac{X_1}{r}$$

$$X_1 = r \sin^{-1} \frac{X_2}{r}$$

$$Y_1 = Y_2$$

$$X_2 = r \sin \frac{X_1}{r}$$

$$\Delta Z_2 = r\left(1 - \cos \frac{X_1}{r}\right) = 2r \sin^2\left(\frac{X_1}{2r}\right)$$

Refer to Fig. 5-6. With tilt

$$X_3 = X_2 \tag{5.1}$$

$$Y_3 = Y_2 \cos t' - \Delta Z_2 \sin t' \tag{5.2}$$

$$\Delta Z_3 = \Delta Z_2 \cos t' + Y_2 \sin t' \tag{5.3}$$

From the film

$$x' = z' \frac{x_2}{y_2} = X_3 \tag{5.4}$$

$$y' = z' \frac{y_2}{z_2} = Y_3 \tag{5.5}$$

$$z' = d_0 + \Delta Z_3 \tag{5.6}$$

The cylinder equation for the easel is

$$r^2 = X^2 + (r - \Delta Z_2)^2 = X^2 + r^2 - 2r\,\Delta Z_2 + \Delta Z_2^2$$

$$X_2^2 = 2r\,\Delta Z_2 - \Delta Z_2^2$$

$$\Delta Z_2^2 - 2r\,\Delta Z_2 = -X_2^2$$

$$\Delta Z_2 = r \pm (r^2 - X_2^2)^{1/2}$$

from which the useful root is

$$\Delta Z_2 = r - (r^2 - X_2^2)^{1/2} = \frac{X_2^2}{r + (r^2 - X_2^2)^{1/2}}$$

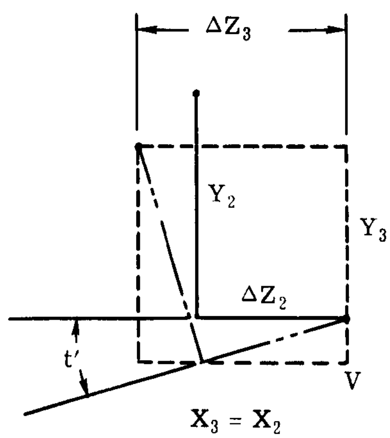


Fig. 5-6 — Displacement after tilt

From Eqs. 5.4 and 5.1

$$X_3 = z'\left(\frac{x_2}{z_2}\right) = X_2$$

and

$$z' = X_2\left(\frac{z_2}{x_2}\right)$$

From Eq. 5.6

$$\Delta Z_3 = z' - d_0 = X_2\left(\frac{z_2}{x_2}\right) - d_0$$

From Eq. 5.5

$$Y_3 = z'\left(\frac{y_2}{z_2}\right) = X_2\left(\frac{z_2}{x_2}\right)\left(\frac{y_2}{z_2}\right) = X_2\left(\frac{y_2}{x_2}\right)$$

From Eq. 5.2

$$Y_3 = Y_2 \cos t' - \frac{X_2^2}{r + (r^2 - x_2^2)^{1/2}} \sin t'$$

Rearranging terms, we obtain

$$y_2 \cos t' = \frac{X_2^2}{r + (r^2 - X_2^2)^{1/2}} \sin t' + X_2\left(\frac{y_2}{x_2}\right)$$

Multiplying by sin t′, we have

$$y_2 \sin t' \cos t' = \frac{X_2^2}{r + (r^2 - x_2^2)^{1/2}} \sin^2 t' + X_2\left(\frac{y_2}{x_2}\right)\sin t' \qquad (5.7)$$

From Eq. 5.3

$$\Delta Z_3 = Y_2 \sin t' + \frac{X_2^2}{r + (r^2 - X_2^2)^{1/2}} \cos t'$$

Rearranging and multiplying by cos t′ yields

$$y_2 \sin t' \cos t' = -\frac{X_2^2}{r + (r^2 - x_2^2)^{1/2}} \cos^2 t' + X_2\left(\frac{z_2}{x_2}\right) \cos t' - d_0 \cos t' \qquad (5.8)$$

Subtracting Eq. 5.7 from Eq. 5.8, we have

$$0 = -\frac{X_2^2}{r + (r^2 - X_2^2)^{1/2}} + X_2\left(\frac{z_2}{x_2} \cos t' - \frac{y_2}{x_2} \sin t'\right) - d_0 \cos t' \qquad (5.9)$$

Rearranging terms yields

$$-\frac{X_2^2}{r + (r^2 - X_2^2)^{1/2}} + X_2\left(\frac{z_2}{x_2} \cos t' - \frac{y_2}{x_2} \sin t'\right) = d_0 \cos t'$$

We now introduce the auxiliaries

$$z_2 \cos t' - y_2 \sin t' = C \qquad (5.10)$$

$$d_0 \cos t' = C_2 \tag{5.11}$$

Substituting Eqs. 5.10 and 5.11 into Eq. 5.9, we get

$$-\frac{X_2^2}{r + (r^2 - X_2^2)^{1/2}} + \frac{X_2}{x_2} C_1 = C_2 \tag{5.12}$$

Rearranging terms, we obtain

$$X_2^2 - \left(\frac{X_2}{x_2} C_1 - C_2\right)[r + (r^2 - X_2^2)^{1/2}] = 0$$

$$X_2^2 - \left(\frac{X_2}{x_2} C_1 - C_2\right) r = \left(\frac{X_2}{x_2} C_1 - C_2\right)(r^2 - X_2^2)^{1/2} \tag{5.13}$$

Squaring Eq. 5.13 yields

$$X_2^4 - 2X_2^2\left(\frac{X_2}{x_2} C_1 - C_2\right) r + \left(\frac{X_2}{x_2} C_1\right)^2 r^2 = -X_2^2\left(\frac{X_2}{x_2} C_1 - C_2\right)^2 + \left(\frac{X_2}{x_2} C_1\right)^2 r^2 \tag{5.14}$$

Dividing Eq. 5.14 by X_2^2, we obtain

$$X_2^2 - 2\left(\frac{X_2}{x_2} C_1 - C_2\right) r = -\left(\frac{X_2^2}{x_2^2} C_1^2 - 2\frac{X_2}{x_2} C_1 C_2 + C_2^2\right)$$

Rearranging terms, we have

$$X_2^2\left(1 + \frac{C_1^2}{x_2^2}\right) - 2\frac{X_2}{x_2} C_1 (r + C_2) = -2C_2 r - C_2^2$$

$$\left(\frac{X_2^2}{x_2^2} x_2^2 + C_1^2\right) - 2\frac{X_2}{x_2} C_1 (r + C_2) = -C_2(2r + C_2)$$

$$\left(\frac{X_2}{x_2}\right)^2 - 2\frac{X_2}{x_2}\left[\frac{C_1(r + C_2)}{x_2^2 + C_1^2}\right] = -\frac{C_2}{x_2^2 + C_1^2}(2r + C_2) \tag{5.15}$$

Solving Eq. 5-15 for X_2/x_2, we get

$$\frac{X_2}{x_2} = \frac{C_1(r + C_2)}{x_2^2 + C_1^2}\left\{1 - \left[1 - \frac{C_2(2r + C_2)(x_2^2 + C_1^2)^2}{(x_2^2 + C_1^2)C_1^2(r + C_2)^2}\right]^{1/2}\right\}$$

$$= \frac{C_1(r + C_2)}{x_2^2 + C_1^2}\left\{1 - \left[1 - \frac{C_2(2r + C_2)}{C_1^2(r + C_2)^2}(x_2^2 + C_1^2)\right]^{1/2}\right\}$$

$$= \frac{C_2}{C_1}\left\{\frac{2r + C_2}{r + C_2 + [r^2 - (x_2^2/C_1^2)(C_2^2 + 2rC_2)]^{1/2}}\right\}$$

$$= \frac{C_2}{C_1}\left\{\frac{2 + C_2/r}{1 + C_2/r + [1 - (x_2/C_1)^2 C_2/r\,(2 + C_2/r)]^{1/2}}\right\} \tag{5.16}$$

then

$$X_2 = x_2\left(\frac{X_2}{x_2}\right) \tag{5.17}$$

From Eq. 5.7

$$Y_2 = \frac{1}{\cos t'}\left[\frac{X_2^2}{r + (r^2 - X_2^2)^{1/2}} \sin t' + \left(\frac{X_2}{x_2} y_2\right)\right] \tag{5.18}$$

From Eq. 5.12

$$\frac{X_2^2}{r + (r^2 - X_2^2)^{1/2}} = \left(\frac{X_2}{x_2}\right)C_1 - C_2 \tag{5.19}$$

Substituting Eq. 5.19 into Eq. 5.18 yields

$$Y_2 = \frac{1}{\cos t'}\left(\frac{X_2}{x_2}\right)y_2 + \left[\left(\frac{X_2}{x_2}\right)(C_1 - C_2) \sin t'\right] \tag{5.20}$$

From the initial group of equations

$$Y_1 = Y_2 \tag{5.21}$$

$$X_1 = r \sin^{-1} \frac{X_2}{r} \tag{5.22}$$

Eq. 5.22 is not suited for numerical computation; therefore we expand the $\sin^{-1}$ function into a series and obtain

$$X_1 = r\left[\frac{X_2}{r} + \frac{1}{2 \cdot 3}\left(\frac{X_2}{r}\right)^3 + \frac{1 \cdot 3}{2 \cdot 4 \cdot 5}\left(\frac{X_2}{r}\right)^5 + \ldots\right]$$

$$= r\,\frac{X_2}{r}\left[1 + \frac{1}{2 \cdot 3}\left(\frac{X_2}{2}\right)^2 + \frac{1 \cdot 3}{2 \cdot 4 \cdot 5}\left(\frac{X_2}{r}\right)^4 + \ldots\right]$$

$$X_1 = X_2\left[1 + \frac{1}{2 \cdot 3}\left(\frac{X_2}{r}\right)^2 + \frac{1 \cdot 3}{2 \cdot 4 \cdot 5}\left(\frac{X_2}{r}\right)^4 + \frac{1 \cdot 3 \cdot 5}{2 \cdot 4 \cdot 6 \cdot 7}\left(\frac{X_2}{r}\right)^6 \ldots\right] \tag{5.23}$$

In a general form Eq. 5.23 is expressed as

$$X_1 = X_2\left[1 + \sum_{n=1}^{n} \frac{(2n)!}{2^{2n}(n!)\,(2n + 1)}\left(\frac{X_2}{r}\right)^{2n}\right] \tag{5.23a}$$

With Eqs. 5.21 and 5.23 or 5.23a, the desired easel coordinates are found as a function of the image coordinates, x and y, and the parameters of the rectifier settings.

A program for the computation of easel coordinates from film coordinates and rectifier settings is as follows (refer to Fig. 5-7):

NOTE

The numbers appearing in the following listing refer to the initial listing callout number.

Input:

1. F = focal length of camera
2. x_1 = abscissa of image point along film
3. y_1 = ordinate of image point along film
4. t' = tilt angle of easel, degrees
5. d_0 = distance from lens center to easel center
6. r = radius of curvature of easel

7. 4 in radians
8. Sin 7 = $\sin t'$
9. Cos 7 = $\cos t'$
10. $5 \times 9 = d_0 \cos t' = C_2$
11. $10{:}6 = C_2/r$
12. $11 + 1.000 = 1.000 + C_2/r$
13. $12 + 1.000 = 2.000 + C_2/r$
14. $2{:}1 = x_1/F = \phi$ radians
15. Sin 14 = $\sin \phi$
16. Cos 14 = $\cos \phi$
17. $1 \times 15 = x_2$
18. $1 \times 16 = z_2$
19. $18 \times 9 = z_2 \cos t'$
20. $3 \times 8 = y_2 \sin t'$
21. $19 - 20 = z_2 \cos t' - y_2 \sin t' = C_1$
22. $17{:}21 = x_2/C_1$
23. $22^2 = (x_2/C_1)^2$
24. $23 \times 11 \times 13$
25. $1.000 - 24$
26. $\sqrt{25}$
27. $26 + 12$
28. $10{:}21 = C_2/C_1$
29. 28×13
30. $29{:}27 = X_2/x_2$
31. $17 \times 30 = X_2$
32. $31{:}6 = X_2/r$
33. $32^2 = (X_2/r)^2$
34. $33^2 = (X_2/r)^4$
35. $33{:}6.000$
36. 34×0.0750
37. $1.000 + 35 + 36$
38. $37 \times 31 = X_1$ print out
39. $30 \times 3 = (X_2/x_2)\, y_2$
40. $30 \times 21 = (X_2/x_2)\, C_1$
41. $40 - 10 = (X_2/x_2)\, C_1 - C_2$
42. $41 \times 8 = 41 \sin t'$
43. $42 + 39$
44. $43{:}9 = Y_1$ print out

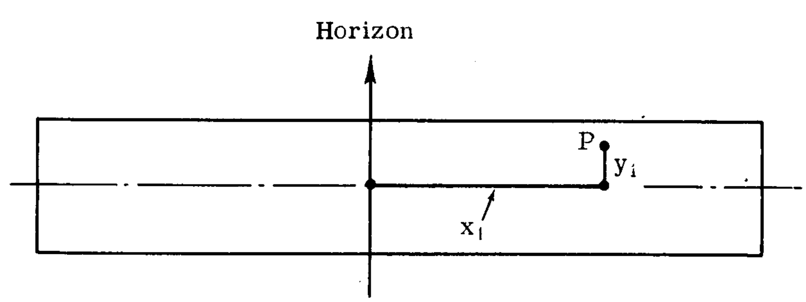


Fig. 5-7 — Diagram for computation of easel coordinates

6. TECHNICAL CONSIDERATIONS

Among the design problems encountered in the development of the Gamma I instruments were the following:

1. Formulation of a mathematical expression to translate the imagery taking parameters into the various easel, lens, Scheimpflug, and exposure settings. As a corollary to this requirement, it was necessary to design and fabricate a unique slide rule to handle the developed mathematical expression.

2. Design, development, and fabrication of a lens having the difficult to achieve capabilities of wide angle, high resolution, nearly distortionless field, and proper spectral response required to meet the printer's exacting reproduction specifications. Theoretical analysis indicated that most of the required capabilities were at (or beyond) the current state of the art, so that final design and fabrication of a suitable lens was not accomplished without difficulties and delays.

3. Design and development of a mechanism for the precise variation of the Scheimpflug angle.

4. Design and development of a curved copy easel whose curvature and relative position could be precisely varied (with a high degree of repeatability) for variations of camera altitude and tilt.

5. Design and development of a mechanism for varying the tilt of the easel. It was required that this mechanism be extremely precise and repeatable.

Mechanisms, techniques, and concepts utilized in previously produced [redacted] rectifiers were included (where applicable) in the design and manufacture of the Gamma I instrument, either as is or with slight modifications.

The Gamma I instruments produced under this contract have demonstrated capability to meet or exceed all contract specifications, and have served to advance the state of the art by a substantial margin. Factors and functions which appear to be subject to future improvement have been pointed out and described in Section 4.

Specific details of the various aspects of the design and manufacture are described and illustrated in the following subsections, not necessarily in the order of their relative importance.

6.1 OPTICAL CONSIDERATIONS

This section includes a discussion of the controlling parameters of the optical system: the lens, tilt considerations, and illumination system.

6.1.1 Lens Design

The initial design study undertaken for this project pointed out that there were no commercially

available lenses that would maintain the required resolution over the wide field angle necessary to
25X1 accommodate the tilt and scan ranges. [redacted] undertook a special lens design for a 15.8-inch-focal-length lens with an aperture from f/9 to f/11 at the desired conjugates.

As the design progressed, it became apparent that the necessary size of the glass elements precluded the use of American made glass, and it was necessary to purchase the raw glass from
25X1 [redacted] This increased the time needed to fabricate and test the final lens.

The lens consisted of eight elements arranged in an approximately symmetrical configuration (see Fig. 6-1). There were two sets of cemented elements used in this design, and a fixed aperture of f/9 was selected. The test phase for the lens indicated that the required resolution was not being generated because of the cemented element surfaces, and that the nodal point separation increased and shifted as the field angle was increased. These inadequate results dictated the necessity of a lens redesign to accomplish our objectives.

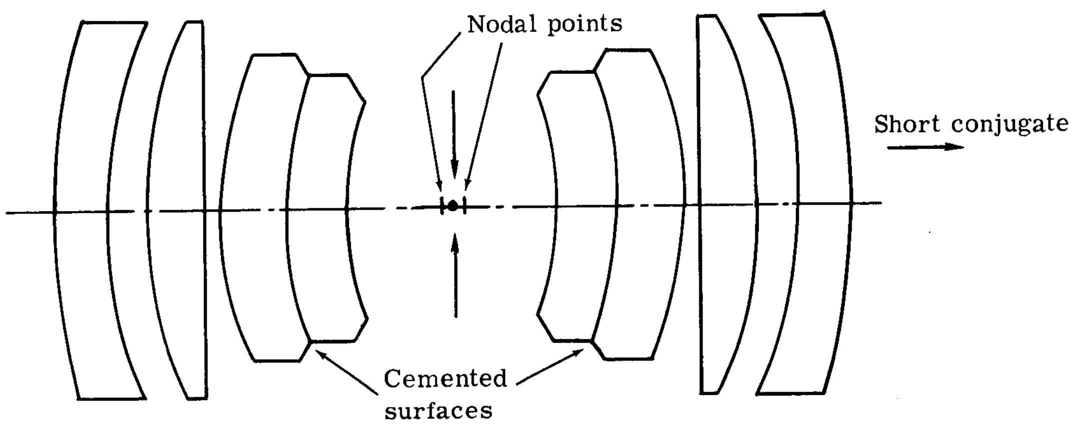
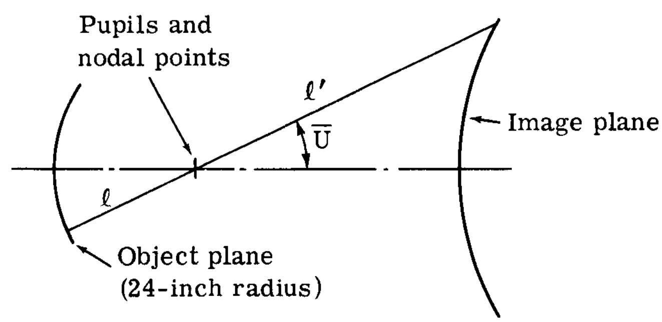


Fig. 6-1 — Gamma IA lens configuration

Although the Gamma IA lens was originally designed to conform to standard lens design procedures, it did not give the required results. A reevaluation of all test data indicated that the design of a lens with the following characteristics should be undertaken:

1.	Focal length	15.8 inches
2.	Object format	70-millimeter film on short conjugate
3.	Magnification (central)	1.93× on axis to 2.7× at the edge of the field (see Fig. 6-2)
4.	Lens semifield	26.1 degrees
5.	Output film	Eastman Kodak type 5427
6.	Spectral range	4358-Å region
7.	Speed	f/12 (accommodations to be made for a variable aperture to accommodate f/18, f/15, f/12, f/10, and f/9)

8.	Resolution	80 lines per millimeter at short conjugate for field angles from 0 to 12 degrees; 50 lines per millimeter minimum for field angles from 12 to 22.8 degrees; no requirement from 22.8 to 26.1 degrees.
9.	Distortion	±0.010 inch maximum at long conjugate over a 22.8-degree field angle
10.	Nodal points	Coincident
11.	Entrance and exit pupils	Coincident
12.	Curvature of field	Tolerable if distortion requirement is met on a curved field
13.	Object to nodal point distance	24.0 inches



$$M = \frac{\ell'}{\ell} = \frac{\ell'}{24 \text{ inches}}$$

$\bar{U}$, degrees	M, inches
0	1.93
10	2.01
15	2.13
20	2.33
26	2.73

Fig. 6-2 — Schematic of first-order characteristics of Gamma IB

Requirement 10 is necessary for the Gamma I concept. Requirement 11 causes the distortion to be the same on a curved field as on a flat one, and at the same time minimizes the variation of astigmatism with conjugate.

A schematic diagram of the first-order properties of the lens is shown in Fig. 6-2. The design approach utilized was based on the standard double gaussian configuration with 6 elements. Since the normal lens of this type has separated nodal points as well as separated pupils, two negative elements were added (one at the front and one at the rear) to accomplish this task.

The correction of the lens was accomplished with the [redacted] automatic correction program on our CDC-924 computer. The procedure differed from the usual one due to the variable conjugates as well as coincident cardinal points. Since variations of third-order distortion with conjugate are proportional to the spherical aberration of the pupil, the latter aberration had to be corrected to a small value. At all times in the design phase, nodal points and pupils were made coincident. It should be pointed out that the variation of astigmatism with conjugate is minimized by the coincident pupils; the remaining variation of coma with conjugate is small but irreducible due to the magnification range and focal length selected. The major residual aberration is the variation of astigmatism with color, which will be controlled by the spectral bandpass of an interference filter. A filter with a half-width of 100 Å at 4358 Å was selected to conform with the spectral response of the output film. 25X1

The lens assembly is illustrated in Fig. 6-3. The configuration shown in Fig. 6-4 illustrates the physical arrangements of the lens elements.

6.1.2 Distortion Measurement and Resolution Test

The following discussion outlines the procedures used to obtain values of transverse distortion as a function of field angle for the Gamma IB lenses as well as values of photographic resolution at these field angles.

Background

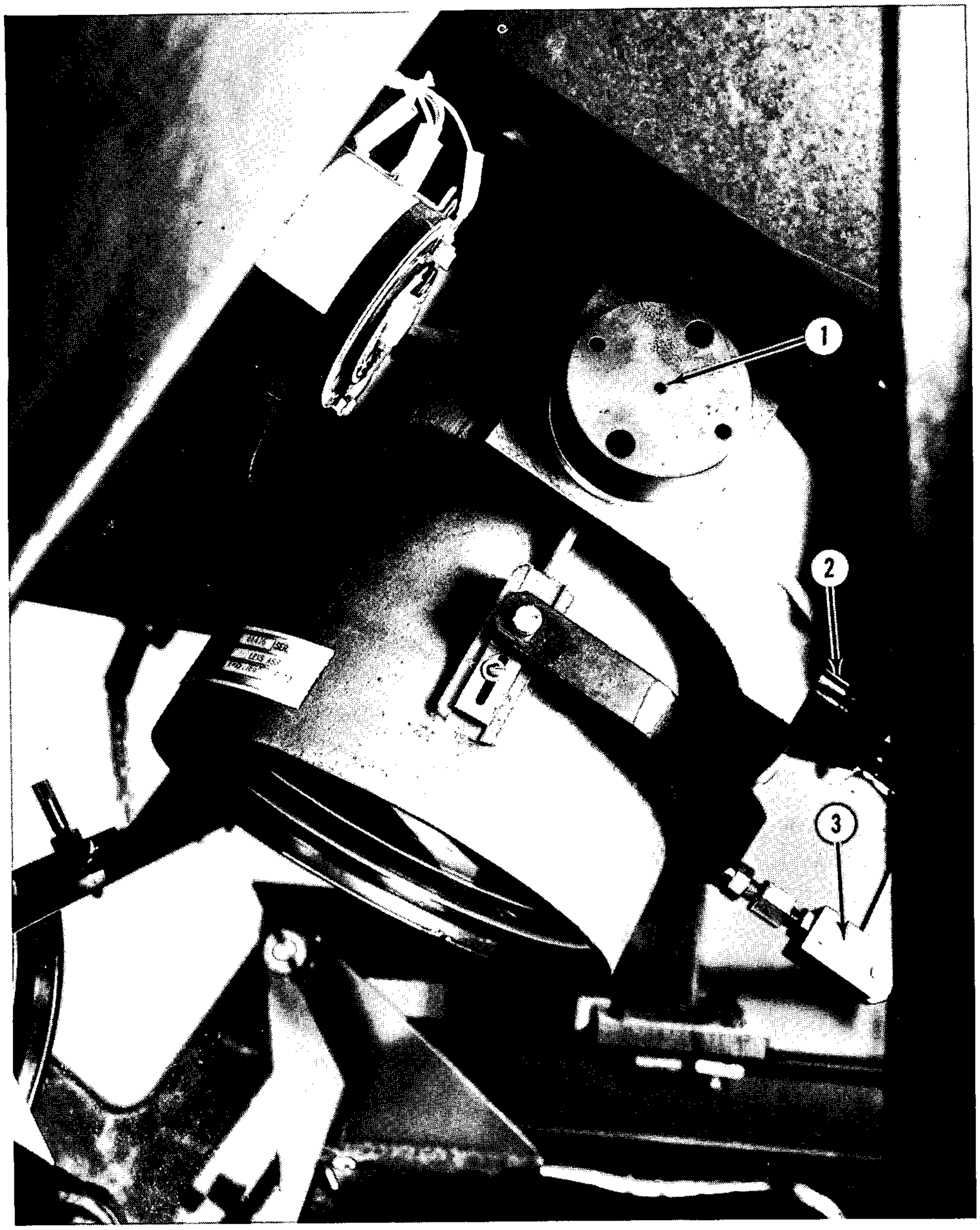
In Fig. 6-5, the entrance pupil, exit pupil, and both nodal points are coincident at point N for a perfectly constructed lens.

If the lens in Fig. 6-5 is free of distortion, a ray leaving point source, P_1, will be imaged at P_1' after passing through N, and a ray leaving point source, P_2, on radius, R, will be imaged at P_2' after it passes through N. The locus of image points from point source, P_1, P_2, ..., P_n, is drawn approximately to scale in Fig. 6-5, using a magnification at nadir of 2×. It can readily be seen that the distance between N and P_n grows rapidly as the angle, γ, is increased. Fig. 6-6 shows the locus of image points which results from rotating the lens without disturbing the location of the point source, P. The rotation takes place about an axis through N perpendicular to the optical axis of the lens. Angular field position, γ, indicates the amount of rotation. As mentioned previously, the distance, d, grows rapidly as the semifield angle increases. For a real lens, i.e., one which is not perfectly constructed and which does have distortion, the situation in Fig. 6-7 prevails. Point N is an effective nodal point or center of rotation and the image of P occurs at $P_n'^*$ as shown. Measurement of the resultant transverse distortion, X, and the minimization of the maximum excursion is the object of this test.

25X1 The test is performed on the "super" [redacted] optical bench in a manner similar to that shown in
25X1 Fig. 6-8. The standard "super" [redacted] bench procedure was followed to ensure that the microscope axis and the lens axis are coincident. (This axis is called the z axis.) The coordinate system shall be as shown in Fig. 6-8 with the additional requirement that the x direction shall be perpendicular to the plane of the diagram.

The light source to be used for this test shall be similar to that shown in Fig. 6-9. A cone of light not greater than f/9 will be imaged at the center of the pinhole, which shall have a diameter no greater than 0.00025 inch. An interference filter peaked at 4358 ± 5 Å shall be used; the filter shall be visually aligned perpendicular to the optical axis.

 25X1



1 Scheimpflug axis
2 Focus control axis
3 Scheimpflug control linkage

Fig. 6-3 — Lens assembly

 25X1

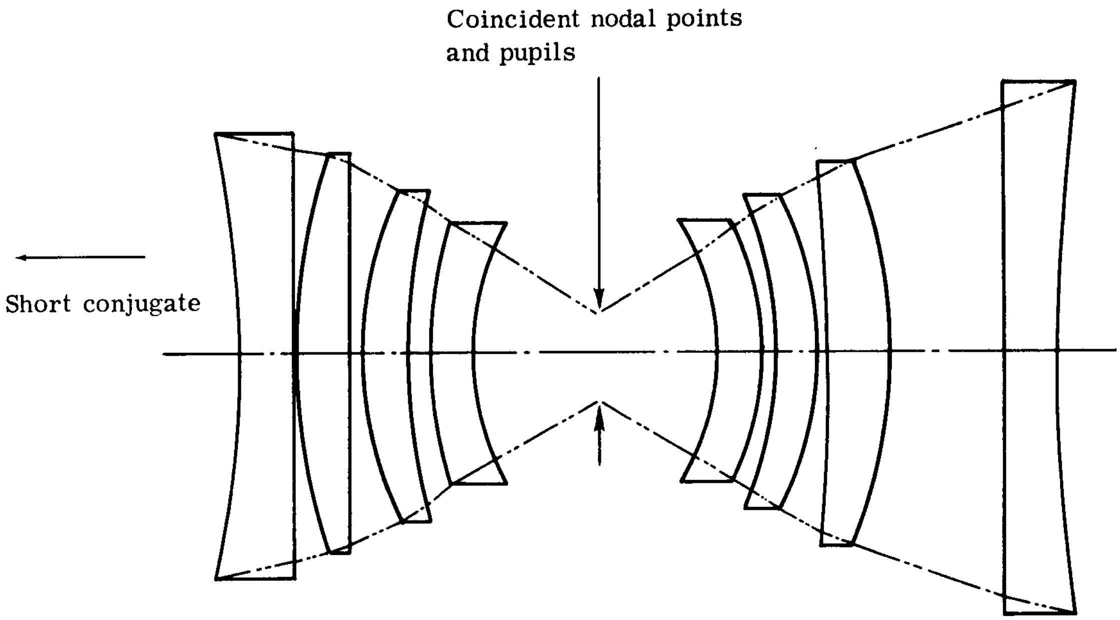


Fig. 6-4 — Gamma IB lens configuration

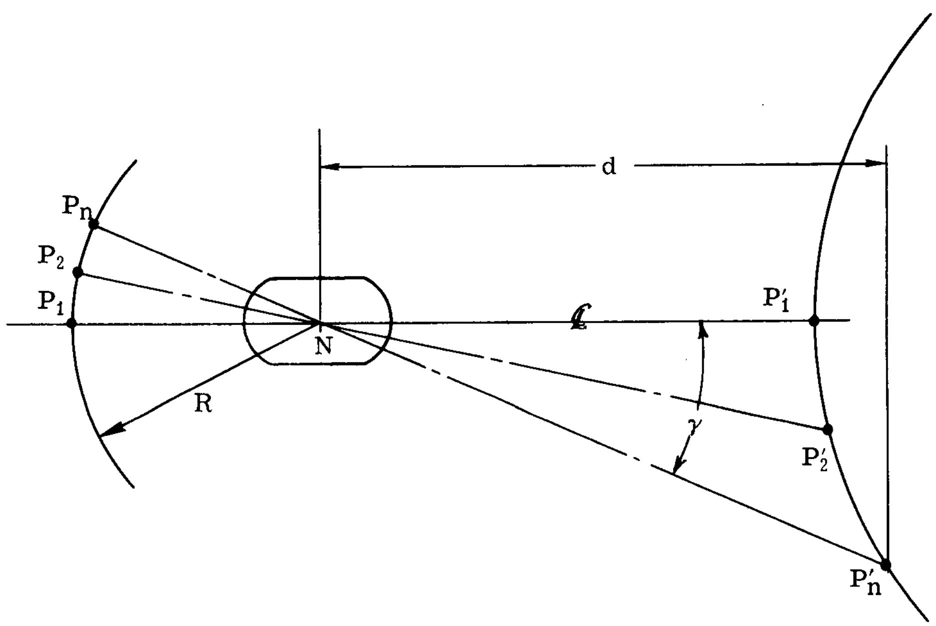


Fig. 6-5 — Lens diagram showing the locus of image points from a point source

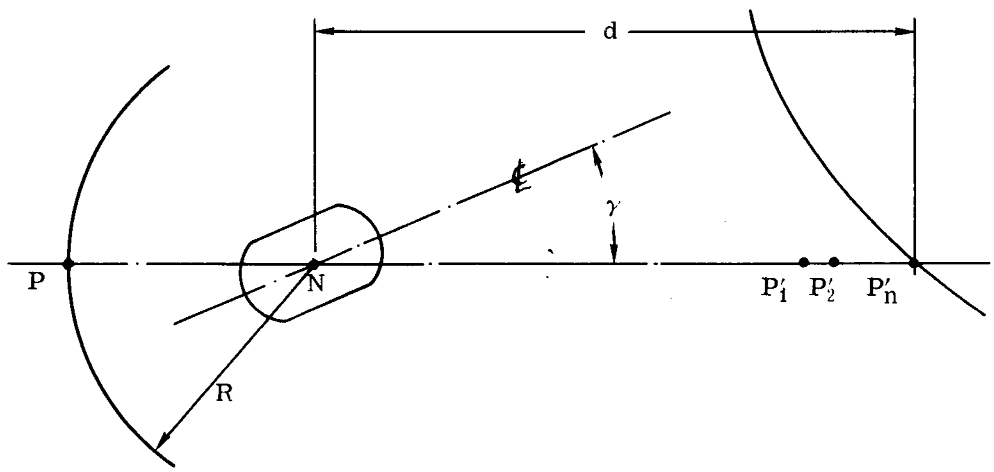


Fig. 6-6 — Lens diagram showing the locus of image points which results from rotating the lens

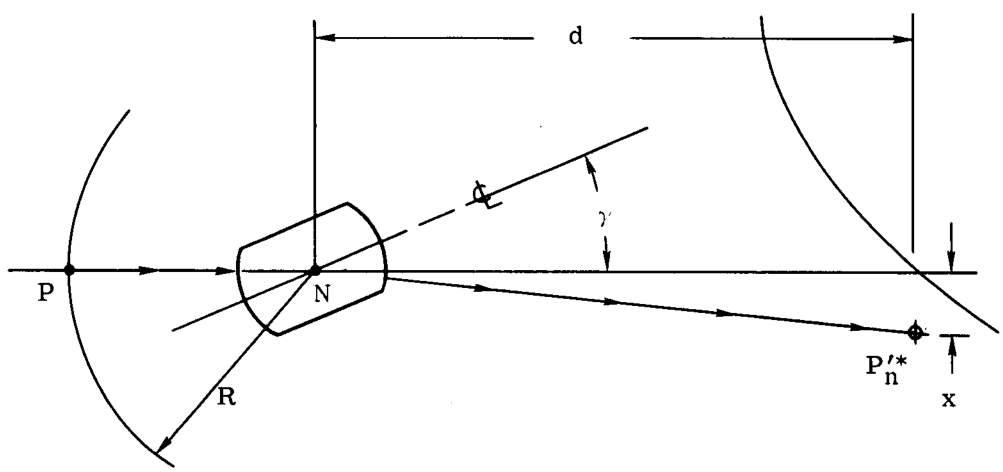


Fig. 6-7 — Lens diagram showing situation resulting from rotating a lens which has distortion

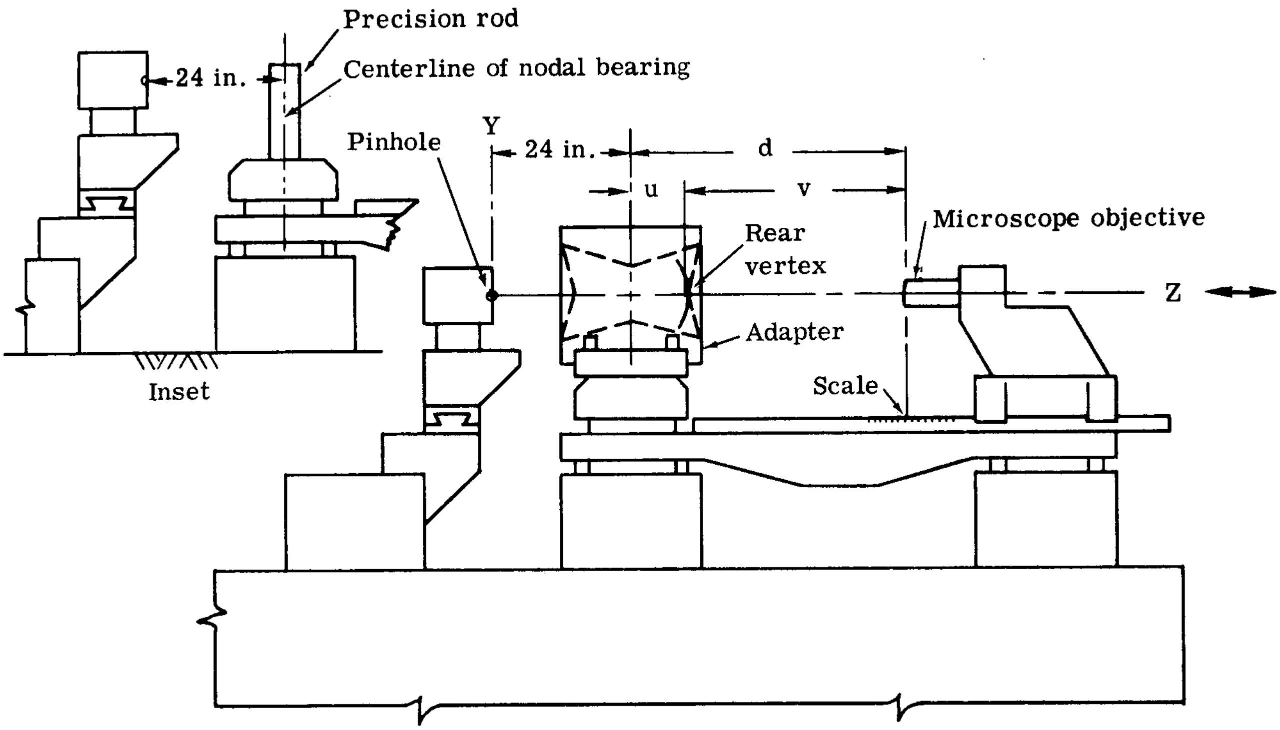


Fig. 6-8 — Test setup for "super" [redacted] optical bench 25X1

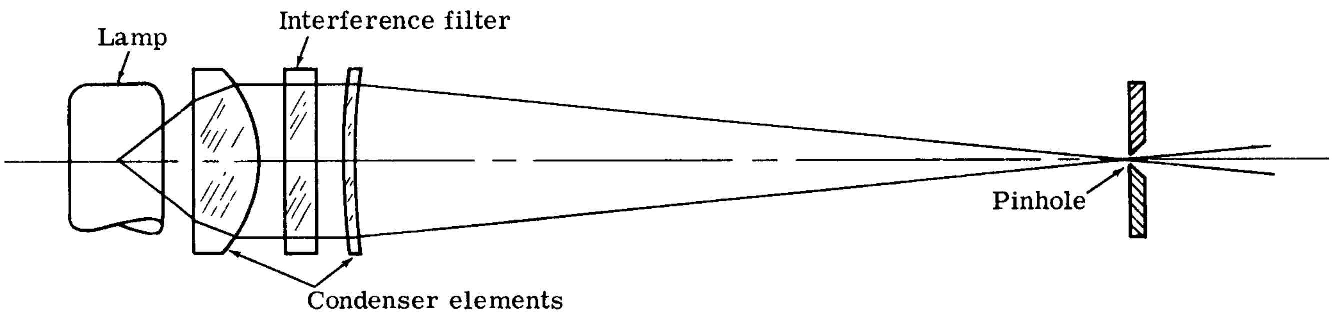


Fig. 6-9 — Light source for lens test setup

Mensuration Procedure

The mensuration procedure to determine distortion is as follows:

1. With the lens on axis, set the nodal points of the lens over the axis of the nodal slide bearing.

2. Adjust the microscope along the z axis until a sharp image of the point source core can be seen through the microscope.

3. Record the distance, d (see Fig. 6-8)

4. Rotate the lens about the centerline of the nodal bearing until the lens is off axis γ degrees (γ is the angular field position).

5. Increase d until an image of the core appears in the microscope objective.

6. If X is measured out of the plane of the paper in Fig. 6-8, determine the distance from the origin which locates the position of the core.

7. Adjust d to optimize the core image when X is being determined.

8. Record d and X. The value X is the distortion for the angular field position, γ, for which it is measured.

9. Repeat the above for the following values of γ: plus and minus 5, 10, 12.5, 15, 17.5, 20, and 23.4 degrees.

10. Plot distortion as a function of field angle.

11. If the plot is not symmetrical about the distortion axis such that distortion values for any $\pm\gamma$ differ by less than 0.005 inch, adjust the alignment and repeat all the above steps until this condition is satisfied (see Fig. 6-10).

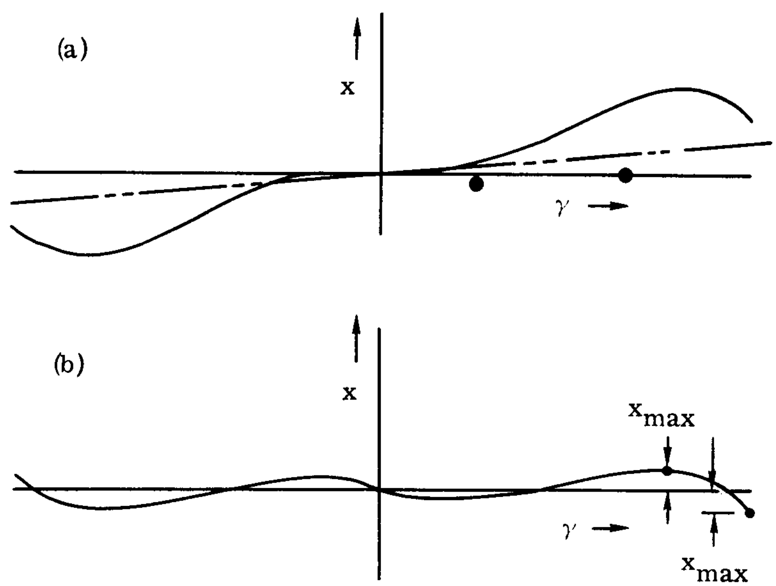


Fig. 6-10 — Distortion plot as a function of field angle. (a) Symmetrical distortion. (b) Balanced symmetrical distortion

12. When a symmetrical plot of distortion versus field angle has been obtained, adjust the position of the lens along the z axis with respect to the centerline of the nodal bearing so that the negative and positive values of distortion are brought to a minimum value. For example, if the distortion were symmetric as shown in Fig. 6-10, adjust the lens along the z axis until the balanced symmetric occurs.

13. When the results are satisfactory, make two repeatability runs at each field angle.

14. When longitudinal optimization and repeatability have been satisfied, the location of the trunnion axis with respect to the rear vertex of the lens must be measured to within 0.001 inch maximum. During the final repeatability run, for a minimum of three values of d, record the value of V, i.e., the distance from the rear vertex to the image plane of the microscope objective terminus of d. The difference between d and V will indicate the exact location at which the lens must be rotated to obtain balanced symmetric distortion.

Resolution Test

The resolution tests will be performed on the "super" [redacted] bench as shown in Fig. 6-8 with the following exceptions: 25X1

1. The pinhole shall be removed and replaced by a high contrast USAF 1951 resolution target.
2. The microscope shall be replaced by a film holder. The film used shall be Kodak type 5427.

The procedure for obtaining resolution results on film will be as follows:

1. When the point of rotation for balanced symmetric distortion and the axis of the nodal bearing are coincident, obtain and record values of best visual focus at field angles of 0, ±5, ±10, ±15, ±20, ±22, ±23, ±24, and ±26 degrees.
2. Replace the microscope with the film holder.
3. Rotate the lens to the proper value of field angle, γ, and the corresponding value of best focus position which shall be designated as zero. Photographic resolution exposures will then be made at the following distances from visual best focus position: 1.5, 1.2, 0.9, 0.6, 0.3, 0.0, −0.3, −0.6, −0.9, −1.2, and −1.5 millimeters.
4. Repeat the above for all field angles stipulated.
5. The resolution requirements must not be less than 90 lines per millimeter on axis, and 60 lines per millimeter at all other field positions.

6.2 MECHANICAL CONSIDERATIONS

The Gamma I Rectifying Printer is a compact, integral unit that transforms and rectifies distorted scale panoramic photography into enlarged, uniform scale, positive prints suitable for map and chart compilation and revisions.

The printer is designed to duplicate, proportionally, the physical and dynamic aspects of the taking system, but in a reverse manner, i.e., the light source sweeps peripherally about the panoramic film plane, projecting an image through the lens onto the printing easel. The easel, which simulates the earth in map scale, is curved to a cylindrical shape whose radius may be varied to simulate the apparent change in earth curvature as a function of altitude and camera tilt angle. The easel may be inclined with respect to the input film plane, to simulate a tilted taking condition.

The panoramic film nadir may be centered on the rectifier's geometric centerline to compensate for roll in the taking system.

The printer's input material is a 500-foot spool of 70-millimeter processed film containing negative panoramic imagery.

The printer's output material is a 500-foot spool of 9½-inch Aerographic Duplicating film, type 5427, that has been exposed with rectified positive images of the input material during operation.

6.2.1 Equipment Configuration

The Gamma I Printer is constructed of a two-section welded aluminum alloy framework. The two sections are fastened together to form a single rigid unit. All components and mechanisms are fastened to the framework at their respective locations, see Fig. 6-11.

The general configuration of the instrument is such that the optical path is folded at an acute angle. This puts the light source (when centered on the platen) and the center of the negative plane at about the eye level of a standing operator.

The negative platen is roughly perpendicular (in a left-right orientation) to the operator's line of sight, with the film plane tilted 30 degrees toward him.

The light source scan arm is positioned so that the light source is perpendicular to the film plane. This projects the light downward and toward the rear of the instrument.

A first surface mirror, mounted parallel to the film plane (in a left-right attitude) is mounted to intercept the beam at about the height of a standing operator's thighs. The mirror reflects the beam toward the operator, in a plane parallel to the floor, onto the easel.

The copy easel may be located at angles from approximately −6 to +21.5 degrees to the beam in the vertical attitude, and parallel to the floor in the left-right attitude.

Orientation of the input film is roughly horizontal, and that of the output film is roughly vertical. These attitudes are modified by the initial and variable tilts of the instrument.

No external skin or film cassettes are provided because: (1) the instrument will be permanently installed in a darkroom, (2) the instrument will not be operated under daylight conditions, and (3) it is necessary for the operator to have quick and convenient access to components.

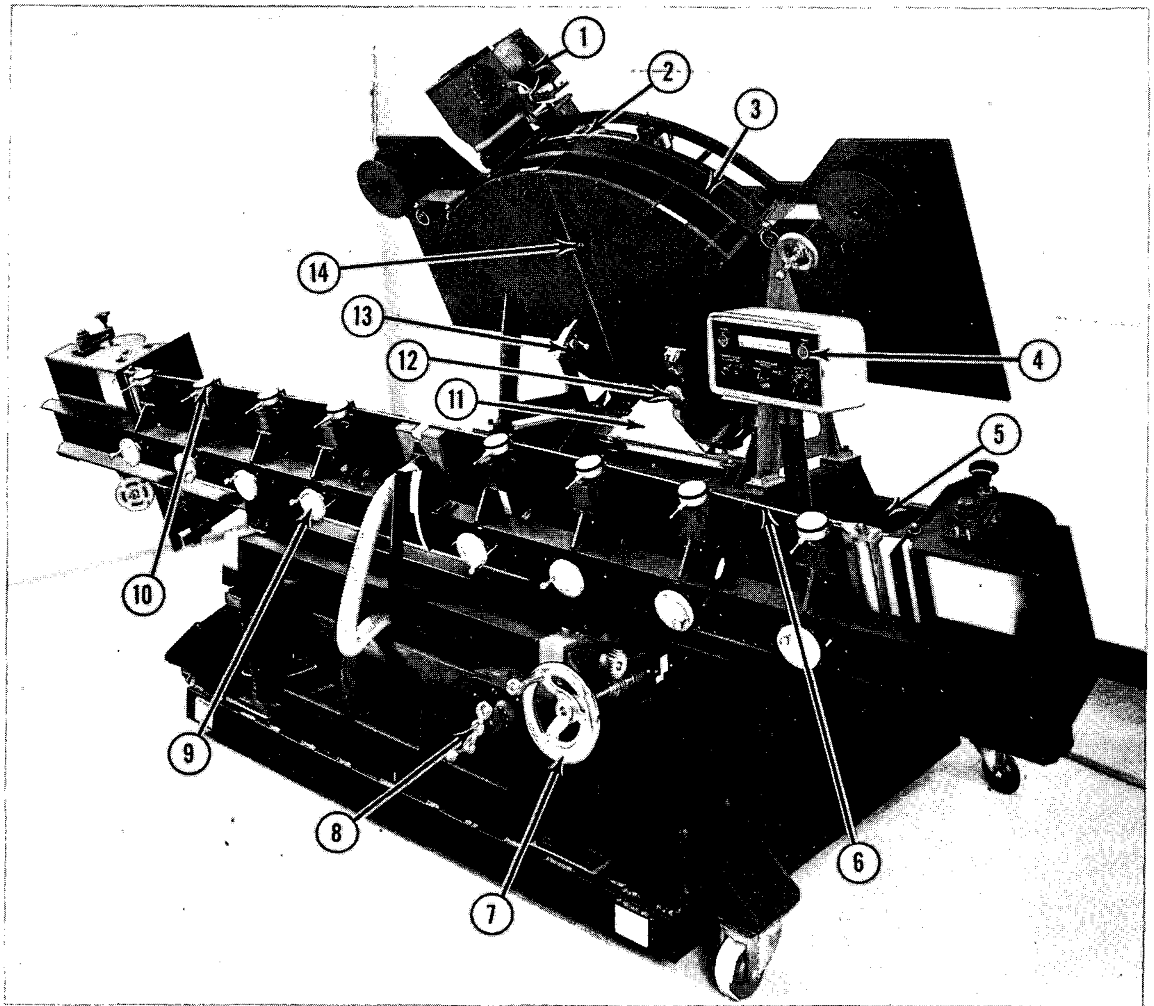
Size, Weight, and Power

The equipment will occupy about 56 square feet of floor space. The basic dimensions are as follows:

Length	10 feet
Front to rear	5 feet 6 inches
Height	5 feet 10 inches

The estimated weight of the equipment is 1,200 pounds, distributed on four casters located in a rectangular pattern approximately 68 by 41 inches.

The equipment consumes approximately 1,100 watts of power and contributes about 3,750 Btu per hour to the ambient temperature.



1	Light source	8	Easel translation control
2	Nadir offset device	9	Easel curvature control
3	Negative film platen	10	Easel curvature indicator
4	Control panel	11	Folding mirror
5	Control chassis	12	Focus control
6	Copy easel	13	Scheimpflug control
7	Easel tilt control	14	Viewing glow lamp lever

Fig. 6-11 — Gamma I Rectifying Printer

6.2.2 Instrument Description

A description of the various components and assemblies of the instrument is given in the following paragraphs.

6.2.2.1 Scan Arm Assembly

The scan arm assembly consists of the projection light assembly, the cooling fan, and the scan arm drive (see Fig. 6-12).

Projection Light Assembly

The projection light assembly consists of a prefocused, ASA type DFR, 500-watt projection lamp; a pair of condenser elements; a 4358-Å interference filter; and an adjustable width slit (see Fig. 6-13).

All components are enclosed in a ventilated metal housing mounted on the upper section of the scan arm. Louvers are inserted in the housing to facilitate the flow of cooling air around the lamp.

The condenser set is of suitable focal length and relative aperture to focus the lamp filament at the lens aperture. The conventional circular shape of the condenser elements is modified by slabbing them to a central rectangular shape similar to the shape of the required rectangular light beam.

The slit is mounted on the lower section of the lamp housing in close proximity to the film plane. It is located such that the long dimension is perpendicular to the input film length. The slit is manually adjustable through a range of from 0.1 to 5.0 millimeters, but the recommended setting for optimum performance is 1.0 millimeter.

The interference filter is roughly the same size as the modified condenser elements, and it is mounted in line between the condenser elements to modify the light emission to the proper spectral characteristics.

Cooling Fan

The cooling fan is mounted on the scan arm at the rear of the light housing. It is physically connected to the housing by a length of flexible air duct. Isolation mounts are used to reduce the transmission of fan vibrations to the scan arm.

The rotation of the blades and the mounting convention are such that the induced flow draws air through the housing louvers, around the lamp, then exhausts the heated air to the atmosphere.

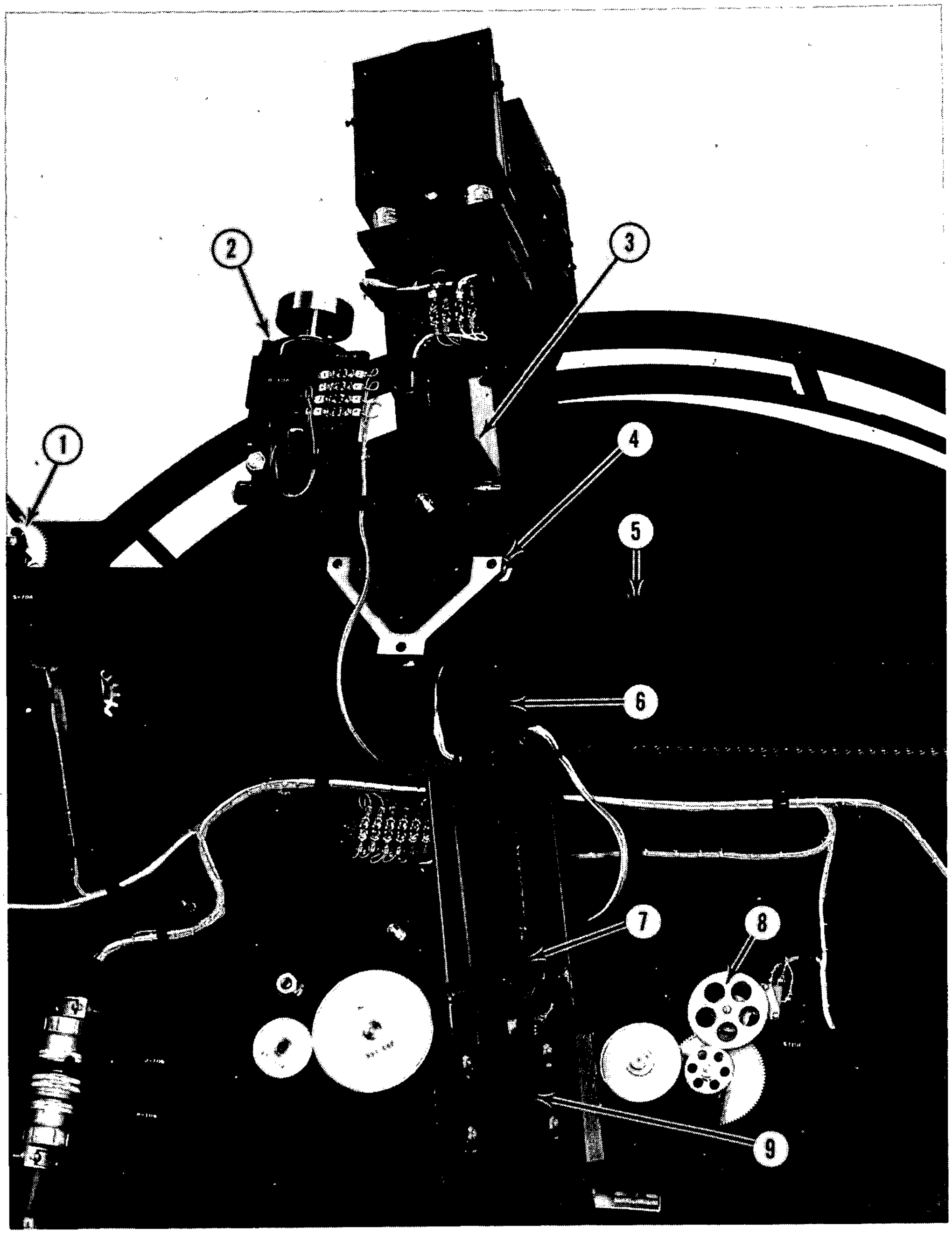
The fan is electrically connected to operate only when the scan arm is at rest.

Scan Arm and Drive Assembly

The scan arm and drive assembly consists of the scan arm, drive motor, drive rail, V ways, exposure control mechanism, limit switches, and counterweight.

The drive arm is pivot mounted to the support plate of the main framework so that when the arm is rotated about the pivot point, the lamp housing swings through an arc concentric with the negative film platen. A spur gear, rigidly fastened to the arm, is a component of the exposure mechanism and focus cam mechanism.

The drive rail is mounted on the rear surface of the support plate so that the arm moves between the plate and the rail.



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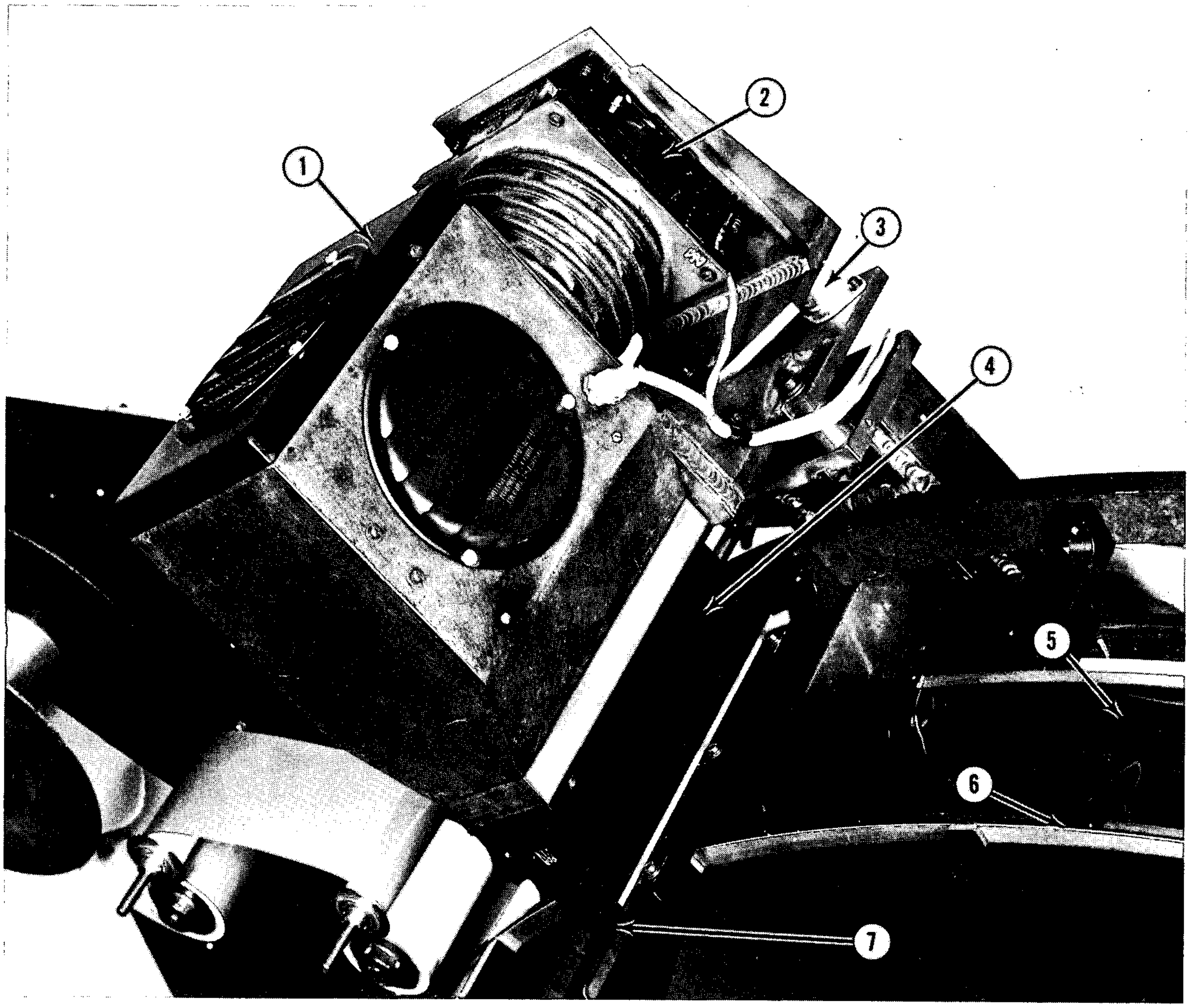
1	Limit switch	6	Drive arm
2	Drive motor	7	Drive arm pivot
3	V ways	8	Exposure control
4	Guide wheel	9	Counterweight
5	Drive track		

Fig. 6-12 — Scan arm and drive assembly



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1 Light source housing
2 Cooling fan
3 Isolation mounts
4 Condenser housing
5 Negative input film
6 Negative film platen
7 Slit width control

Fig. 6-13 — Light source and cooling system

The dc drive motor is mounted on a movable drive carriage that travels along the rail guided by spherical rollers in V ways. The carriage is driven by a friction wheel which in turn is driven by the motor through a helical gear unit.

The drive carriage is coupled to the sliding unit of a V way assembly which is part of the scan arm assembly. As the carriage is translated along the rail, it causes the arm to rotate through its arc by applying force at a continuously varying radius. This serves to modify the angular velocity of the arm so that it is minimum at the ends of its travel and maximum at nadir. This in part serves to produce uniform exposure at the copy easel.

The limit switches mounted at either end of the rail prevent overtravel, and reverse the scan drive circuitry for the next exposure in the opposite direction.

The exposure control consists of a gear mechanism coupled to the armature shaft of a variable transformer that is electrically connected to the drive motor power circuit. As the arm is rotated, the motor voltage variation further modifies the scan velocity, as required, to produce an even exposure at the output film.

The counterweight is fastened to the lower section of the scan arm. Its weight and moment arm are equal to the weight and moment arm product of the upper portion so that the assembly is balanced.

The calculations for the drive motor are presented in Appendix A.

6.2.2.2 70-Millimeter Film Transport System

The 70-millimeter film transport system consists of a set of curved film support rails, a roll control mechanism, film support rollers, two film spindles, two drive rollers, a tension roller, three pressure-wrap rollers, a manual transport control, an endless belt link chain assembly, a magnetic brake, and three torque motors (refer to Figs. 6-14, 6-15, and 6-16).

Film Support

The film support rails are called the negative input platen. The film plane is determined by the support rails and the film support rollers. The roll control mechanism serves to position the input format at the correct roll orientation (refer to Figs. 6-17 and 6-18).

The support rails are cantilever mounted between the main plates such that the center of the 70-millimeter film is 5.000 inches from the front surface of the rear plate. The radius of curvature of their upper (convex) surfaces is set 0.010 inch less than the constant short conjugate of the projection system (24.000 inches).

The tracks are spaced apart so that 0.25 inch of the negative film edge is supported by each, leaving a clear space of 2.25 inches for projection. The rails are equipped with film edge guides, and the inner track has a cutaway section to permit projection of the format edge data and alignment of the fiducial mark with the roll indicator.

The roll control mechanism consists of a scale, a backlighting mechanism, and a sliding indicator. The scale is graduated and marked over an arc length of 210 millimeters (±105 millimeters) with the zero point at the center of the printer. The backlighting mechanism is an electrical glow plate that is swung into position under the negative film to facilitate fiducial alignment; a safety interlock prevents scan arm travel when in the viewing mode. The sliding indicator is of clear plastic with an opaque, scribed, witness mark mounted so that it may move parallel to the scale and perpendicular to it to permit proper film alignment.

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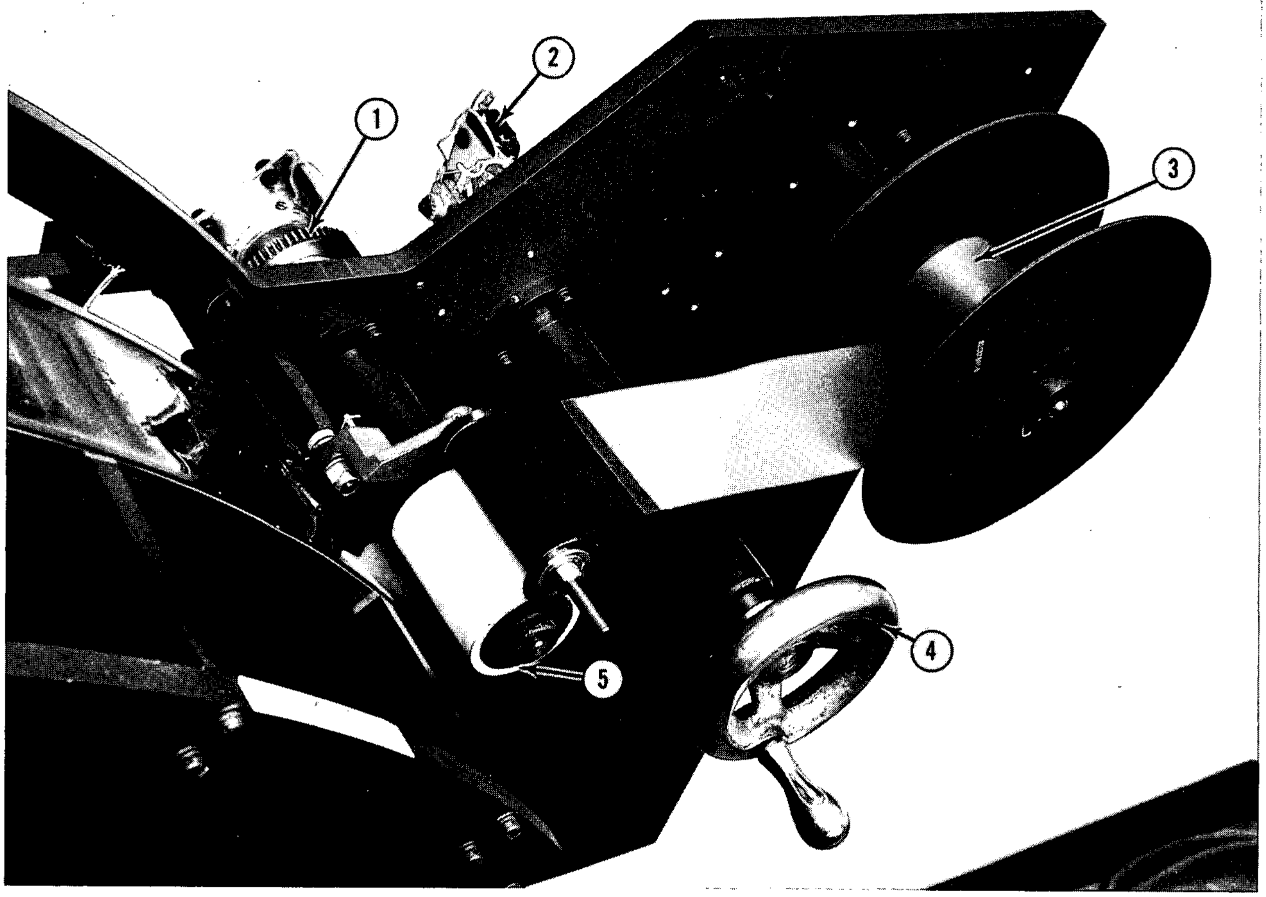

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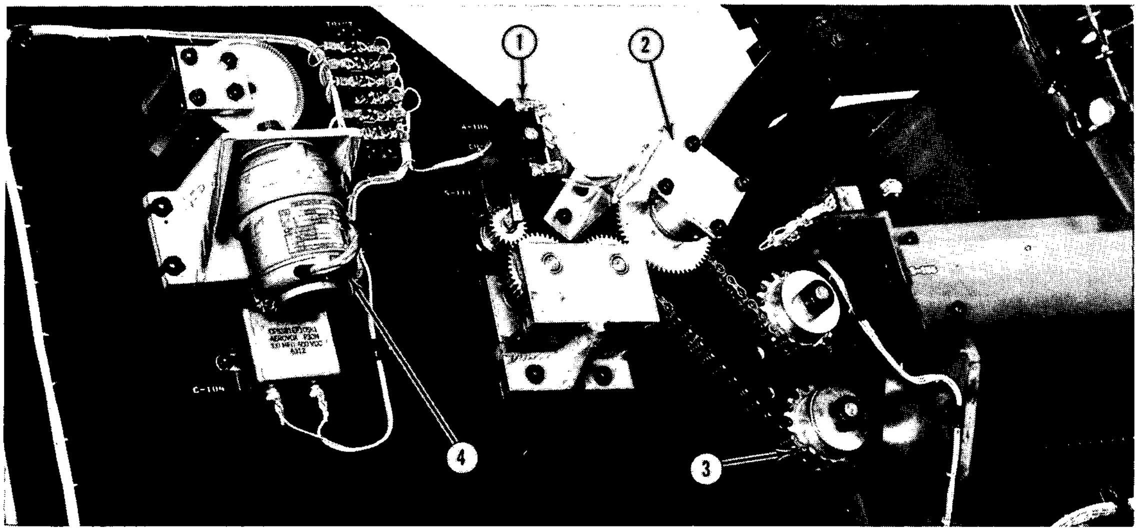
1 Magnetic locking brake
2 Brake control switch
3 Takeup spool
4 Drive handwheel
5 Drive roller

Fig. 6-14 — Negative film transport

25X1



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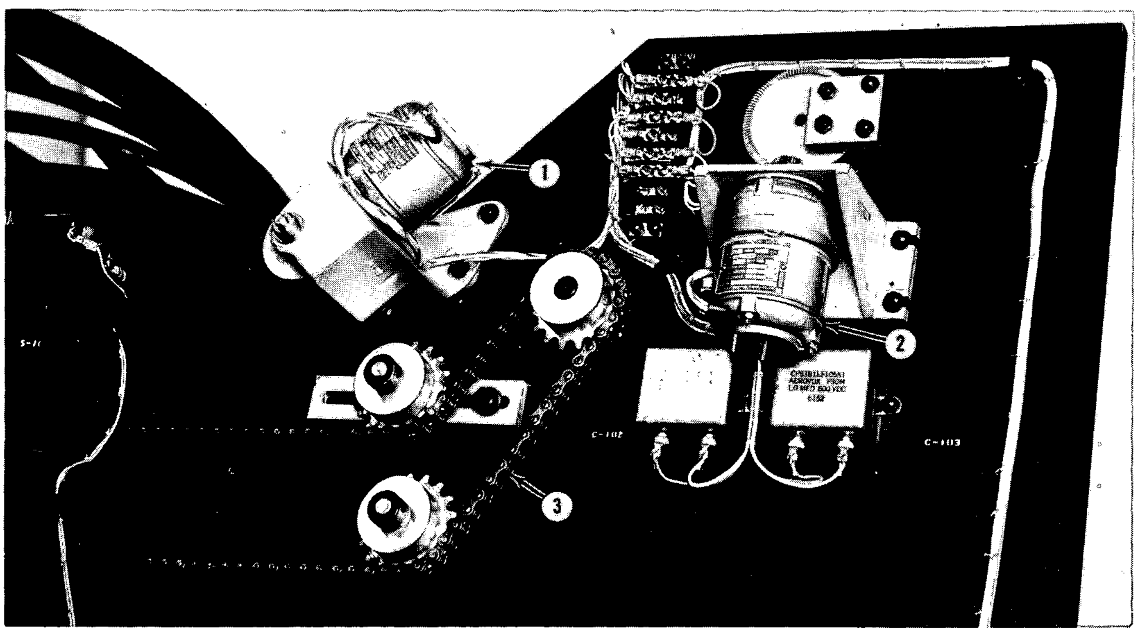
1 Brake control switch
2 Locking brake
3 Drive chain
4 Spool torque motor

Fig. 6-15 — Negative film transport—right reverse side



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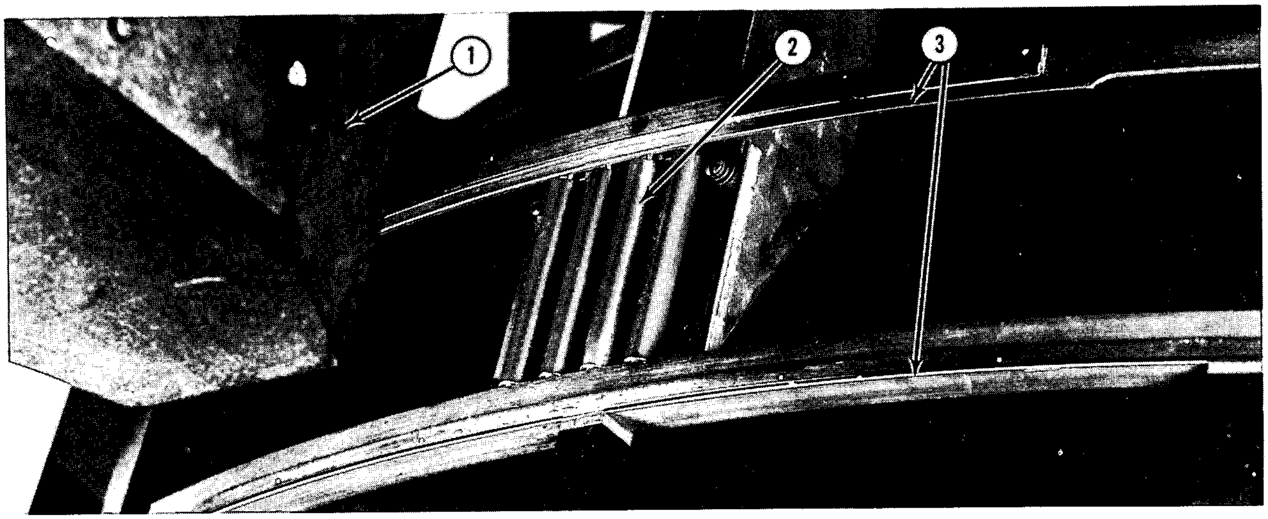
1 Film tension torque motor
2 Spool torque motor
3 Drive chain

Fig. 6-16 — Negative film transport—left reverse side



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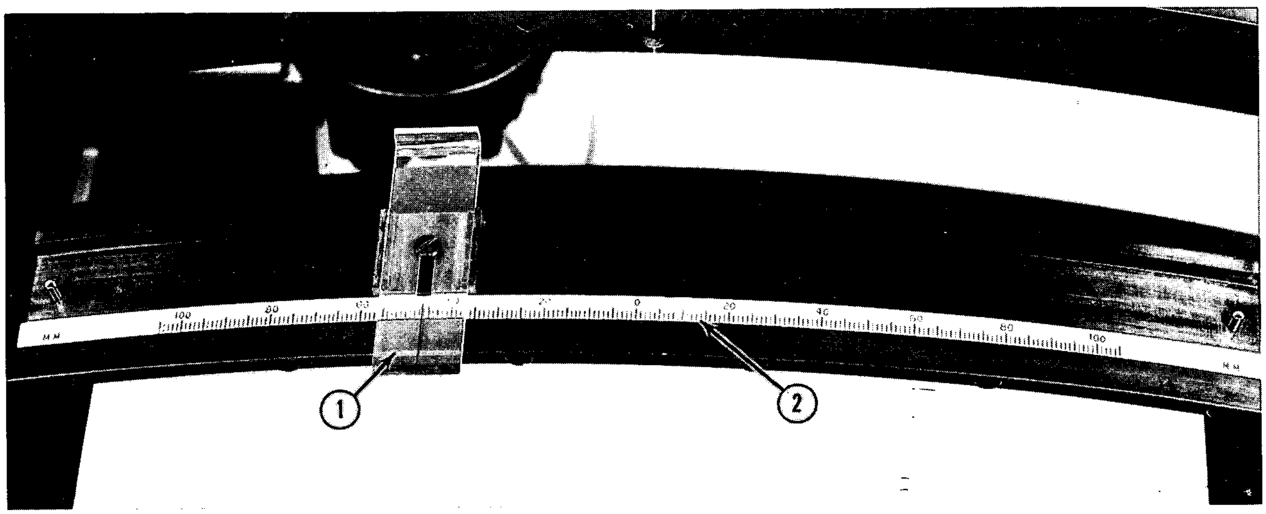
1 Light source
2 Film support rollers
3 Film tracks

Fig. 6-17 — Film platen (condenser system removed)



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1 Nadir offset indicator
2 Nadir offset scale

Fig. 6-18 — Nadir offset device

The film support rollers are four freewheeling rollers mounted to the scan arm so that they travel between the film support rails during a scan cycle. They are positioned to lift the negative film from the rails as the arm scans such that the emulsion side of the film is positioned at the required conjugate distance to maintain geometric fidelity.

Film Transport

The film spindles are mounted at either end of the input platen such that the film travels from a loaded spool (mounted on one spindle) through the platen arrangement, and onto the unloaded spool. Each spindle is coupled through a bevel gear train to a torque motor electrically connected to wind film onto the respective spool with the emulsion side inboard.

A drive roller is mounted at either end of the platen between it and the spindles. Spring loaded pressure rollers are located such that they contact the drive rollers to provide a large angle of wrap for the film. The drive rollers are connected to each other on the rear side of the main plate by sprockets and an endless chain, which is guided and maintained in tension by idler sprockets.

A tension roller, mounted between the left end of the platen and a drive roller (looking from the front), is coupled through a bevel gear train to a torque motor. The motor is electrically connected such that its rotation applies force to the film over the platen. The amount of tension in the film may be regulated by means of a variable transformer located on the control chassis.

The manual control is a handwheel located for right-hand operation. It is connected to the driving sprocket through a mechanical push-pull clutch such that when the clutch is engaged rotation of the handwheel in either direction will cause the film to move correspondingly. The push-pull action of the handwheel also activates a microswitch which controls a magnetic brake connected to the drive roller. When the driving mechanism is engaged (pushed in), the brake is deenergized and the film may be transported; when the mechanism is deenergized (pulled out), the brake is energized to prevent film motion.

Calculations

The 70-millimeter transport system is a manual system employing a handwheel and a friction brake. Assuming a distance between formats of approximately 32 inches and a drive roller diameter of 2 inches, we determine that approximately 5 revolutions of the drive roller will transport the required amount of film. A 3:1 ratio between the handwheel and the drive roller will provide good sensitivity for setting the film to the nadir offset. Fig. 6-19 illustrates the general arrangement of the transport system.

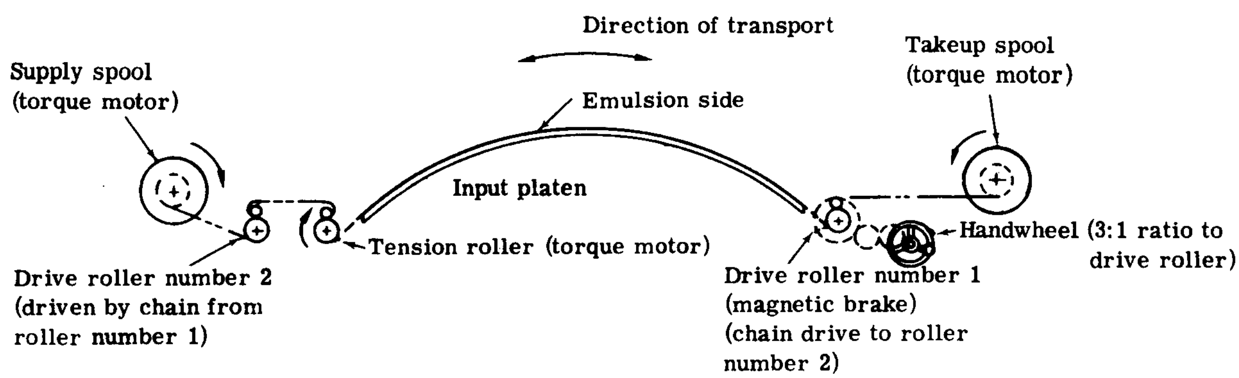


Fig. 6-19 — 70-millimeter negative transport

As a first trial, assume a film spool torque of 3 inch-pounds and select an Elinco torque (FBS-931) with a 6 inch-ounce locked torque. Use an 8:1 gear train between the motor and to obtain the 3 inch-pounds of torque desired.

The film tension between the spool and the first drive roller will vary from a maximum value of

$$\frac{\text{3 inch-pounds}}{\text{1.062-inch radius}} = 2.8 \text{ pounds}$$

to a minimum value of

$$\frac{\text{3 inch-pounds}}{\text{3.8-inch radius}} = 0.79 \text{ pound}$$

As seen from Fig. 6-19, each of the drive rollers has opposing torques transmitted to it. The maximum unbalanced torque occurs when one roller is full and the other empty. The unbalance is $2.8 - 0.8 = 2$ pounds total acting at a 1-inch radius (2 inch-pounds of unbalanced torque).

It is also necessary to provide film tension over the platen by applying a torque to the tension roller. Assume a film tension of 8 ounces; roller torque would then be 8 inch-ounces (2-inch diameter roller). Assume a 3:1 gear train and select an Elinco torque motor (BS-971) with a locked torque of 4.5 inch-ounces. This will allow a maximum available torque of 13.5 inch-ounces or 0.85-pound pull at the periphery of the tension roller. The amount of torque available will be controlled by a variable transformer.

Therefore, the maximum unbalanced torque transmitted to the drive rollers is the geometric sum of the torques produced by the three torque motors, which is $2.8 + 0.85 - 0.8 = 2.85$ inch-pounds. The minimum friction at the number 1 drive roller must exceed 2.85 inch-pounds of torque to prevent film motion.

The force necessary to drive the film from the handwheel (neglecting friction) is

$$\frac{\text{2.85 inch-pounds}}{\text{3:1 ratio}} = 0.95 \text{ inch-pound}$$

Assume a 4-inch diameter handwheel; the force necessary is

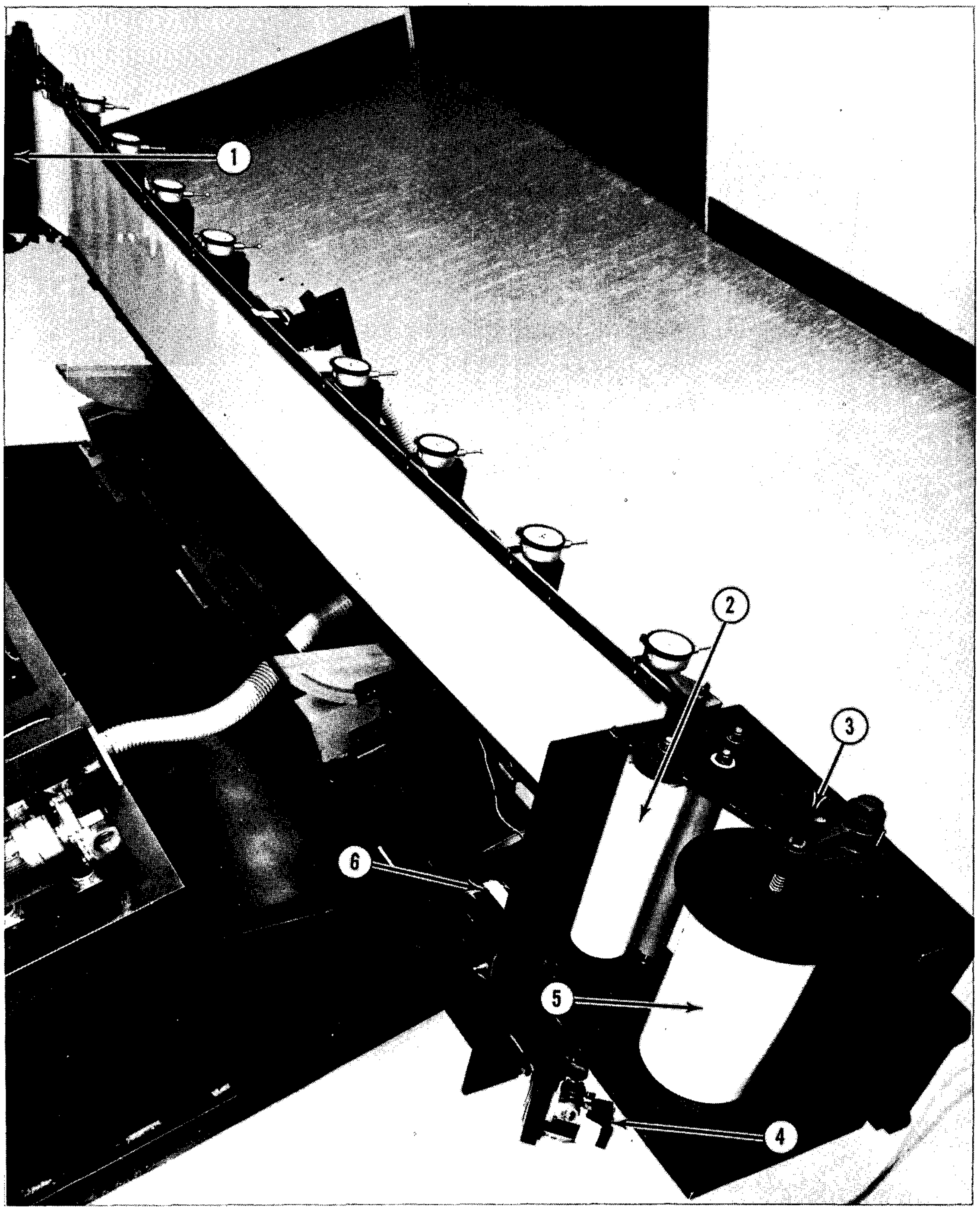
$$\frac{\text{0.95 inch-pound}}{\text{2 inches}} = 0.47 \text{ or } 1/2 \text{ pound}$$

This is not an excessive value, so the foregoing selections and assumptions of motors and gear trains can be considered valid.

6.2.2.3 $9\frac{1}{2}$-Inch Film Transport System

The copy film transport system (Figs. 6-20 and 6-21) comprises the supply and takeup spindle assemblies, the drive mechanism, the easel, and the guide rollers.

25X1



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1	Supply side	4	Variable speed control
2	Drive roller	5	Takeup spool
3	Locating handle	6	Drive motor

Fig. 6-20 — Copy film transport

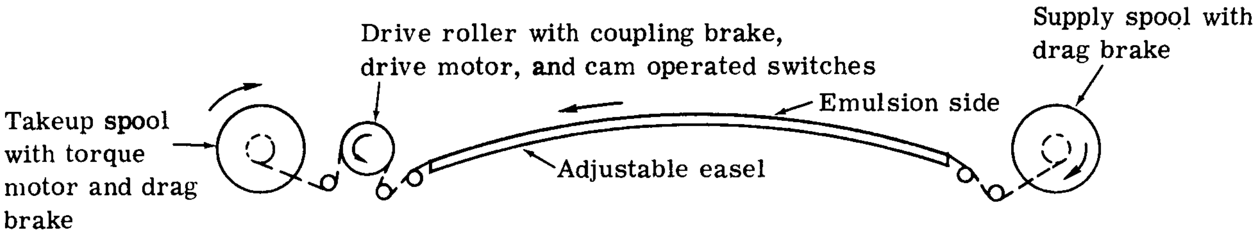


Fig. 6-21 — 9 ½-inch film transport system

The spindle assemblies are mounted at either end of the adjustable curvature easel; the supply assembly is located at the right end and the takeup assembly at the left. Each has a permanently located stub spindle and a spring loaded, movable spindle for the loading and unloading of 500-foot-capacity spools of 9½-inch-wide film. Both stub spindles are equipped with brake drums and an adjustable, constantly acting, band-brake is employed to apply drag to the respective spindle. In addition to the drag brake, the takeup spindle is coupled through a gear train to a torque motor whose rotation will wrap the film onto the spool with the emulsion inboard.

The drive mechanism consists of a neoprene covered drive roller, a drive motor, a gear train, a speed reducer, a cam and switch timing arrangement, and a coupling brake component. The drive roller is coupled to the drive motor and timing unit in such a manner that variation of the reducer output ratio varies the number of rotations of the drive roller. The arrangement serves to alter the amount of film transported per exposure cycle. The system is repeatable and must be reset if a change in transport length is desired.

The guide rollers are freewheeling idlers located to guide the film through the proper path and to provide sufficient wrap around the drive roller.

The combination of drag brakes and takeup torque motors ensures film position in both the power on and power off condition.

The 9½-inch transport system is an automatic system that will transport a predetermined amount of film from a spool with a 500-foot capacity. Assume the following:

Length of film to be transported	84 inches
Time of transport cycle	10 seconds
Diameter of drive roller	3 inches
Tension in film over easel	2 pounds
Revolution of drive roller	$84/3\pi = 8.92$ revolutions
Angular velocity of drive roller	$8.92\ (60)/10 = 53.5$ rpm
Torque required	1.5 inches × 2 pounds = 3 inch-pounds

Assume safety factor of 5; the torque required is 15 inch-pounds. Select a Simplatrol (FFKB50) fixed field coupling brake rated at 16 inch-pounds torque. Select a Bodine motor (B4208-30) rated at 1/20 horsepower, 57 rpm, and 21 inch-pounds torque. Fig. 6-22 schematically illustrates the drive arrangement.

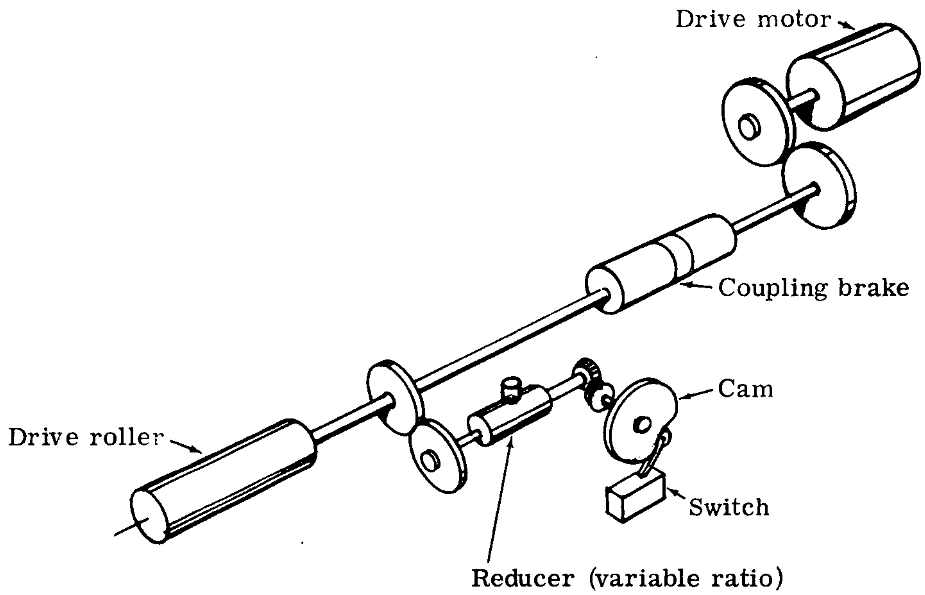


Fig. 6-22 — 9 ½-inch transport drive system

The next step is to select the torque motor. Film velocity is 8.4 inches per second and the rotational velocity of the takeup spool is determined as follows:

$$\text{Maximum} = \frac{(8.4 \text{ inches per second})(60 \text{ seconds per minute})}{2\pi(1.06\text{-inch radius})} = 75.7 \text{ rpm}$$

and

$$\text{Minimum} = \frac{(8.4 \text{ inches per second})(60 \text{ seconds per minute})}{2\pi(3.8\text{-inch radius})} = 21.1 \text{ rpm}$$

From the Elinco torque motor catalog, the average motor speed is 1,100 rpm; therefore, using a gear reduction of 4:1, we obtain a maximum rpm of 275, which gives a factor of about 4.

The torque value for the motor would be found by the product of the static tension and the spool radius divided by the gear reduction

$$\text{Maximum} = \frac{2(3.8)}{4} = 1.9 \text{ inch-pounds}$$

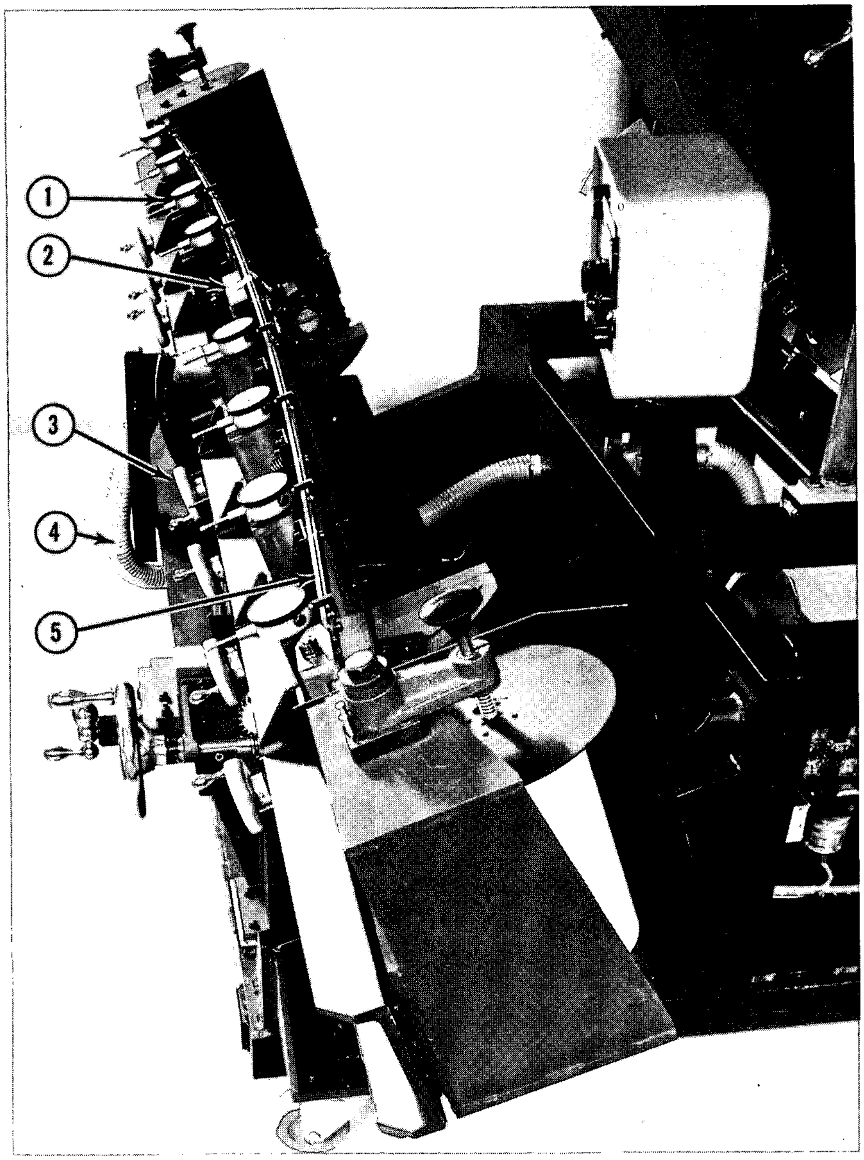
and

$$\text{Minimum} = \frac{2(1.06)}{4} = 0.53 \text{ inch-pound}$$

The motor curve in the Elinco catalog that compares favorably with the torque and rpm limits specifies that motor type G-475 would do the job. The full designation of the motor is Elinco GJRN-475, rated at 32.8 inch-ounces locked torque, continuous duty.

6.2.2.4 $9\frac{1}{2}$-Inch Copy Easel

The copy easel is a thin metal plate shaped to conform to a cylindrical section. The plate has longitudinal grooves coupled through a plenum to an airflow pump so that differential pressure may be created over the surface to hold the film firmly against the easel surface during exposure (see Figs. 6-23, 6-24, and 6-25).



1 Curvature indicator
2 Vacuum manifold
3 Curvature control
4 Vacuum hose
5 Copy easel

Fig. 6-23 — Copy easel (bend represents earth's curvature)

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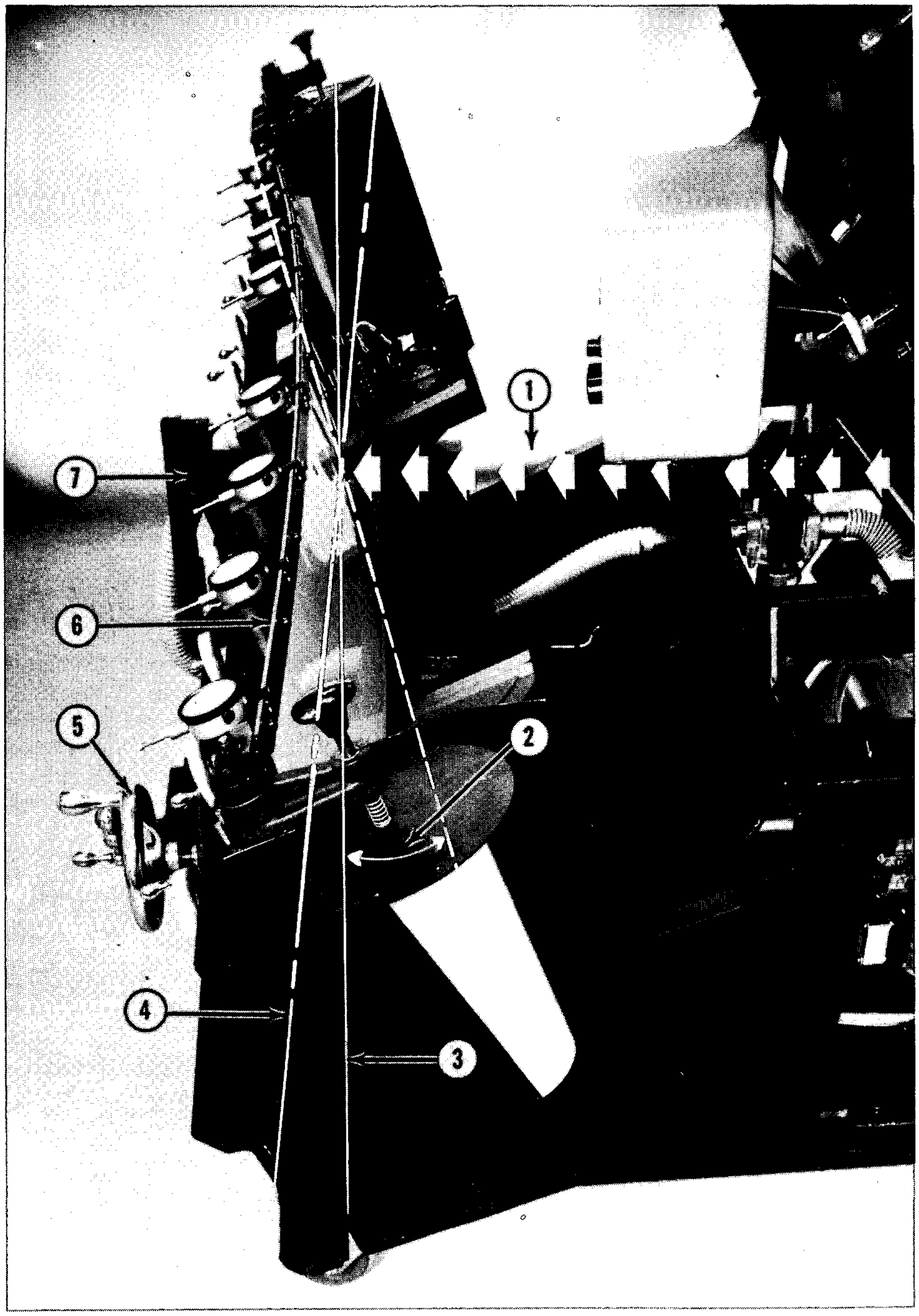

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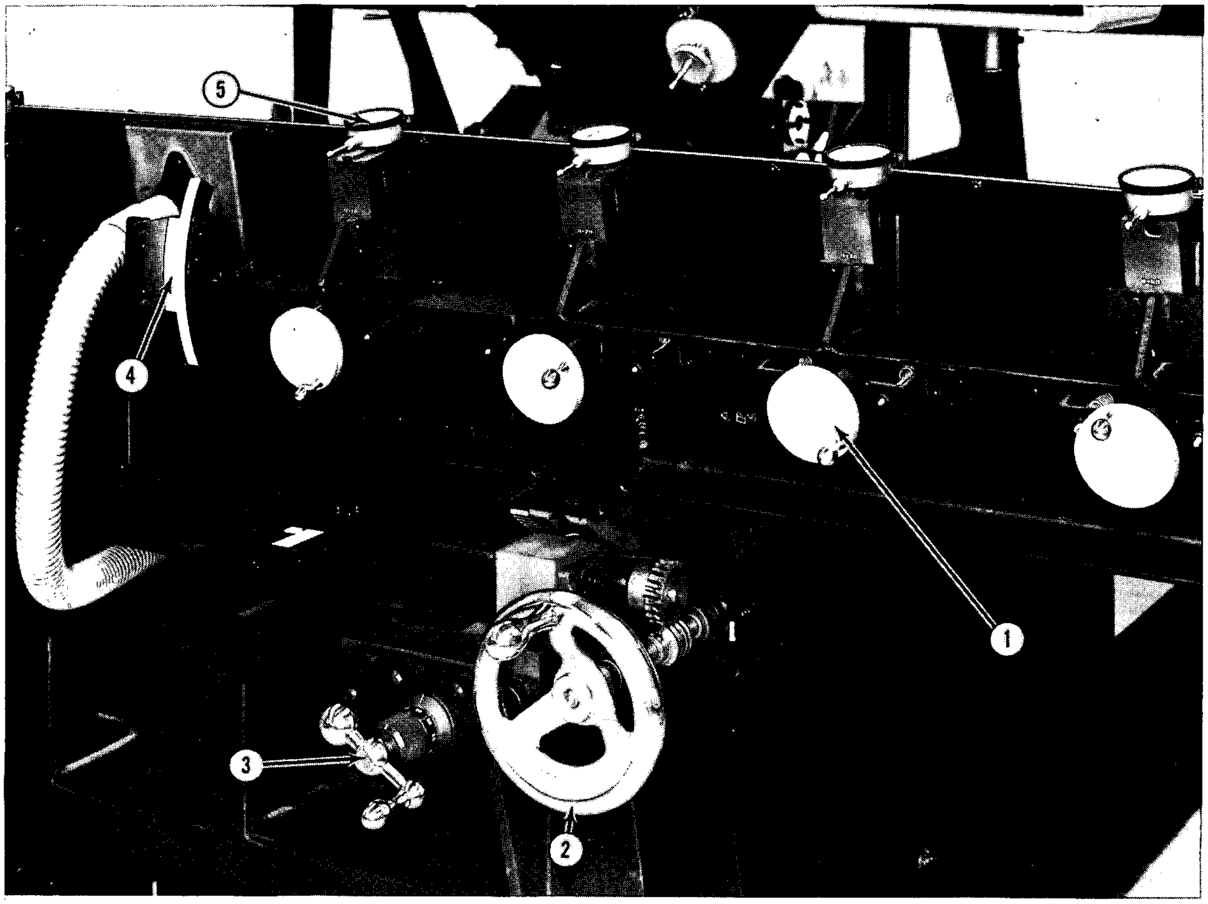
1 Projected beam
2 Tilt angle
3 Vertical reference
4 Tilt axis
5 Easel tilt control
6 Curved easel
7 Easel tilt indicator

Fig. 6-24 — Copy easel showing tilt axis



9879

1 Curvature control
2 Tilt control
3 Translation control
4 Tilt indicator
5 Curvature indicator

Fig. 6-25 — Easel translation, tilt, and curvature controls

The radius of curvature of the plate is varied by adjusting eight screw type control mechanisms (see Fig. 6-26) that exert a force against the rear surface of the plate, which is spring loaded against the controls. Each of the controls has a dial indicator that shows the displacement of its associated section of the plate from an established datum (see Fig. 6-27). The displacement is indicated in 0.001-inch increments. The easel curvature is established as a function of the altitude and pitch of the camera system and information relative to the displacements is obtained from the special slide rule.

The easel plate and radius control mechanisms are mounted on a gimbal type support such that the center of the optical projection is located exactly at the center of the easel where the centerline of rotation passes through the point of tangency with the easel. The easel has the capacity to accommodate input tilt angles from −5 degrees to +20 degrees.

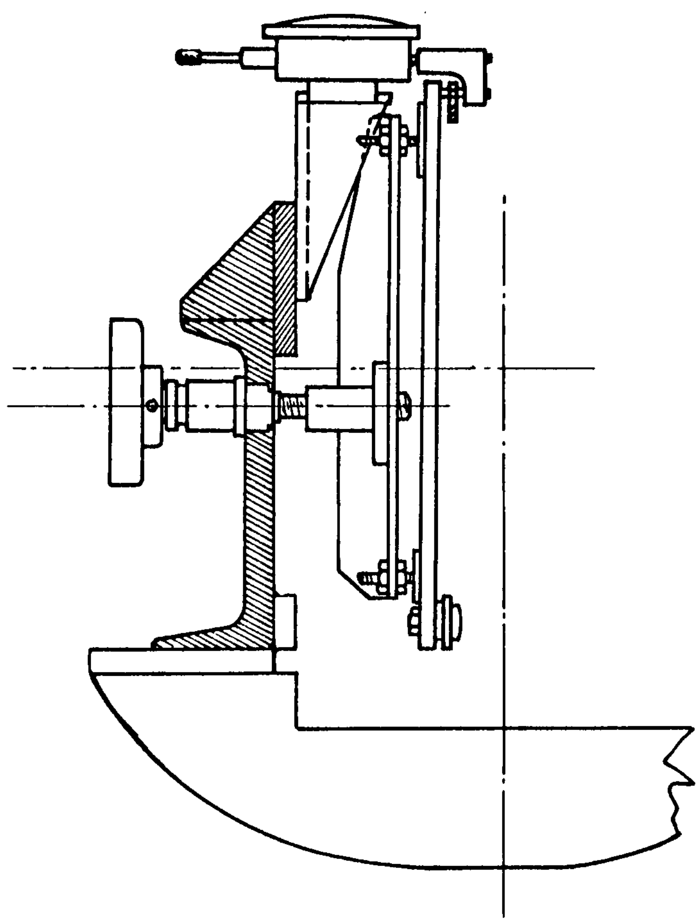
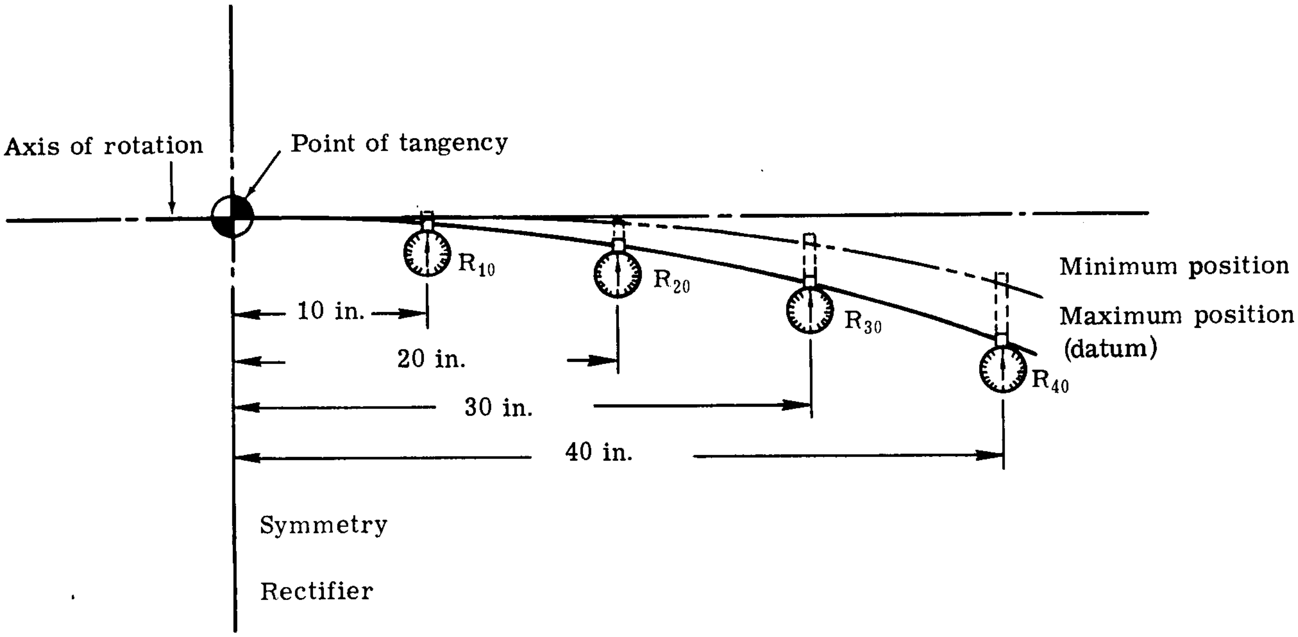


Fig. 6-26 — Control mechanism



	Displacement From Flat to Datum, inches*	Excursion From Maximum to Minimum, inches*
R_{10}	0.086	0.055
R_{20}	0.345	0.221
R_{30}	0.776	0.496
R_{40}	1.381	0.884

*Approximate values.

Fig. 6-27 — Indicator positions

The entire easel assembly (including the film transport) is mounted on a sliding carriage that allows translation along the axis of projection. This arrangement serves to position the easel at the proper location to preserve focus and scale relationships. The main component of this mechanism is a precision machine tool cross-slide mechanism; the position from a zero datum is shown by a micrometer type indicator.

The actual sags or displacements of the plate at the control stations from the datum point are found by the expression (refer to Fig. 6-28)

$$Y = R - \frac{1}{2}(4R^2 - X^2)^{1/2}$$

where Y = sag
R = radius of curvature
X = chordal distance

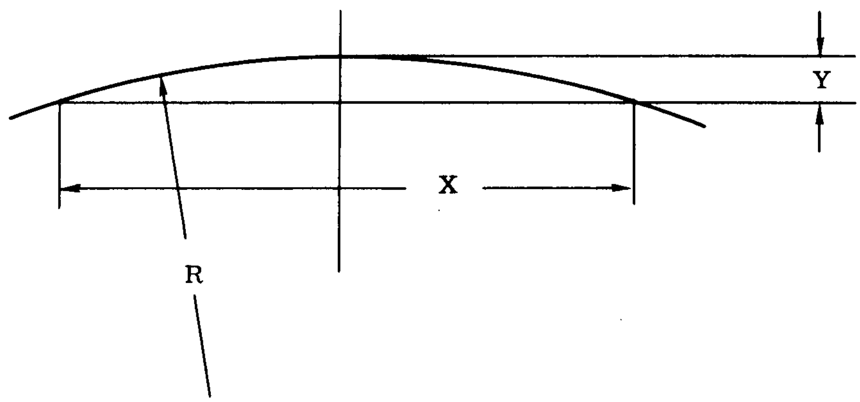


Fig. 6-28 — Copy easel displacement diagram

6.3 ELECTRICAL CONSIDERATIONS

The Gamma I Rectifying Printer was designed to have a minimum of electrical functions to perform the necessary operations. The relay control circuitry employs switching techniques for contact minimization. Plug-in relays were used for maximum reliability and ease of maintenance. Contact protecting diodes were connected across every inductance to minimize contact sparking and noise (refer to Figs. 6-29, 6-30, 6-31, and 6-32).

Safety interlock circuits to minimize operator error are as follows:

1. A cycle interlock relay disables the print switch so that a new print cycle cannot be initiated until the previous print cycle is completed. This relay also disables the viewing lamp to prevent accidental operation during the print cycle.
2. Self-locking relay contacts were employed instead of mechanical latching relays, to ensure circuit reset in case of power loss. This also prevents damage to the equipment.
3. Viewing lamp interlock circuit associated with the viewing lamp disables the scan arm drive motor as soon as the viewing lamp is pushed upward. The viewing lamp will not light until just before its operational position.
4. Unique limit switch synchronizing circuits were used to ensure that the scan arm drive operates at the proper speed and in the proper direction. The variable scan speed is a function of scan arm position and it cannot get out of synchronization unless manually reset.
5. A function light on the control panel indicates the status of the scan cycle.
6. A counter on the control chassis indicates the total number of operational cycles to facilitate maintenance.

6.3.1 Power Consumption

The printer was designed to operate from a 115 ± 5-volt, 60 ± 5-cps power source. The actual voltage and power readings taken on the equipment are as follows:

Voltage at all conditions	120 volts
Power consumption in standby	660 watts

Power consumption during scan cycle	1,020 watts
Power consumption during transport cycle	1,110 watts

The steady operation of the equipment will add approximately 3,400 Btu per hour to the ambient room conditions.

6.4 ENVIRONMENTAL CONSIDERATIONS

The Gamma I Rectifying Printer is a precision mechanical-optical instrument and it must be handled as such to provide optimum performance. It is not necessary to have highly specialized photographic technicians to operate the instrument so long as the operators are careful and conscientious.

The instrument is designed for operation in a darkroom under adequate safelight conditions. The darkroom should be kept under laboratory conditions such that the temperature is maintained at 75 ± 5 °F, at a relative humidity of 50 ± 5 percent.

The room should be adequately proportioned to accommodate the printer, two technicians, a table, two chairs, and a storage cabinet. The approximate size of this room would be 17 by 15 feet (255 square feet of floor area). The air supply should be recirculated to provide adequate ventilation and temperature control. For operation of the equipment, the room should have a 115-volt, 60-cps, single phase, 20-ampere power source connected to a twist lock type of receptacle.

The room must be kept as dust free as possible and the operators must clean the instrument frequently. It should be impressed on the operators that cleanliness and care in operation and maintenance are paramount.

25X1

25X1

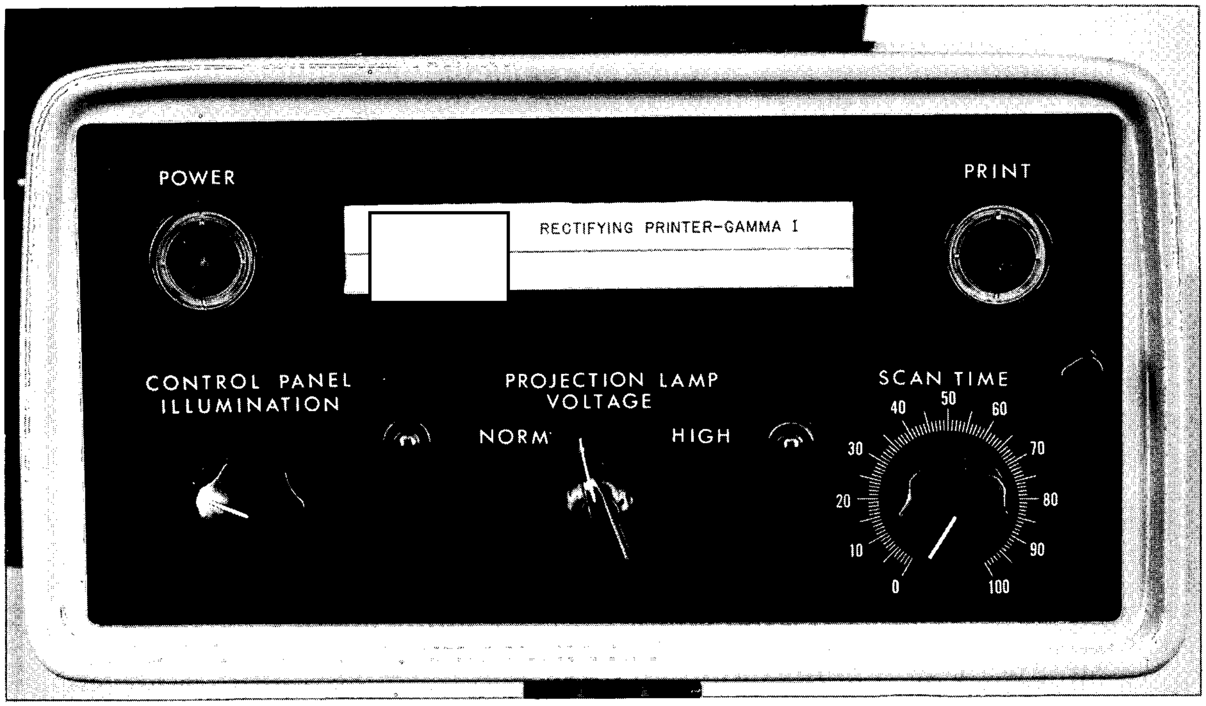


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Fig. 6-29 — Control panel

25X1

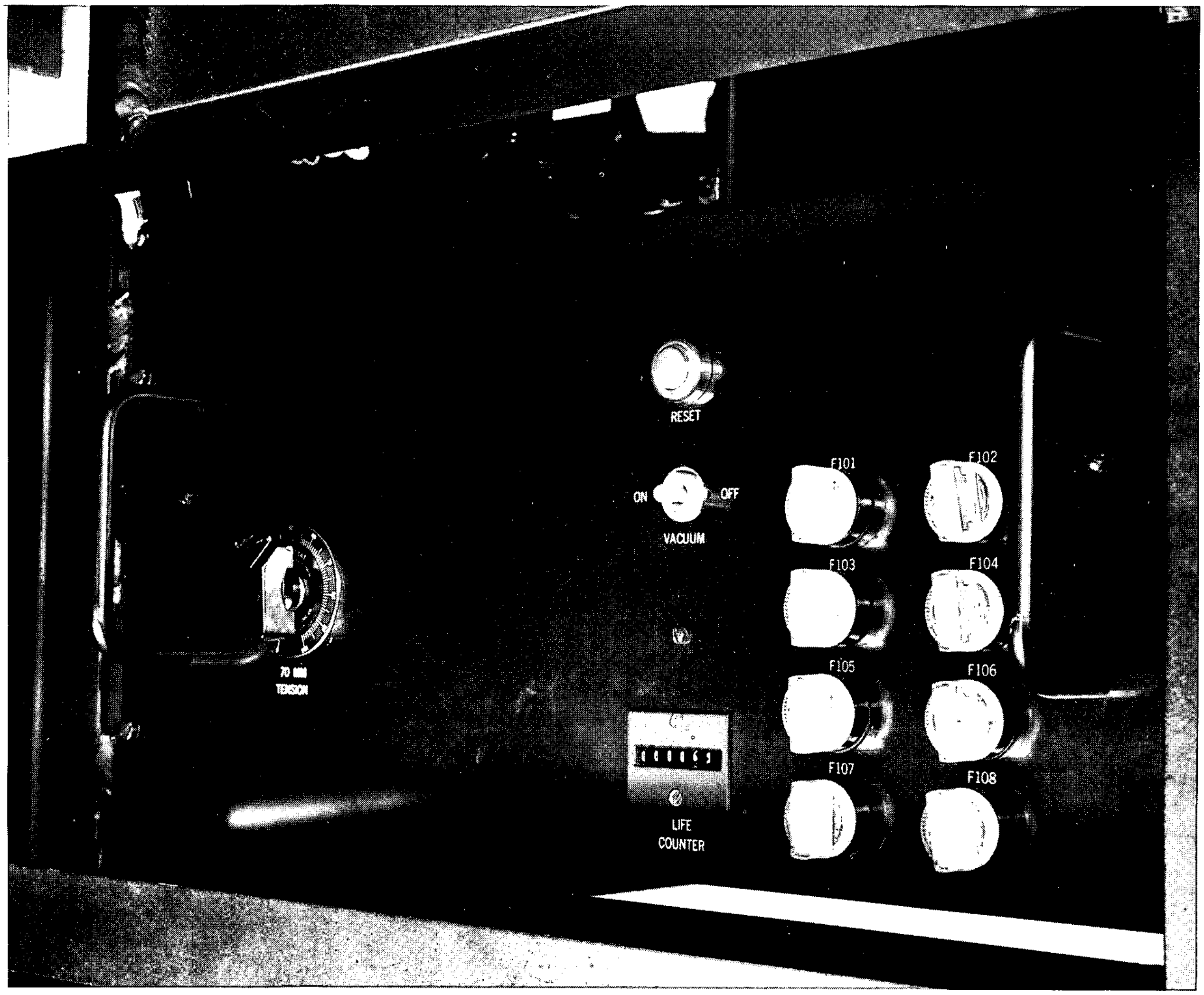

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Fig. 6-30 — Top panel of control chassis

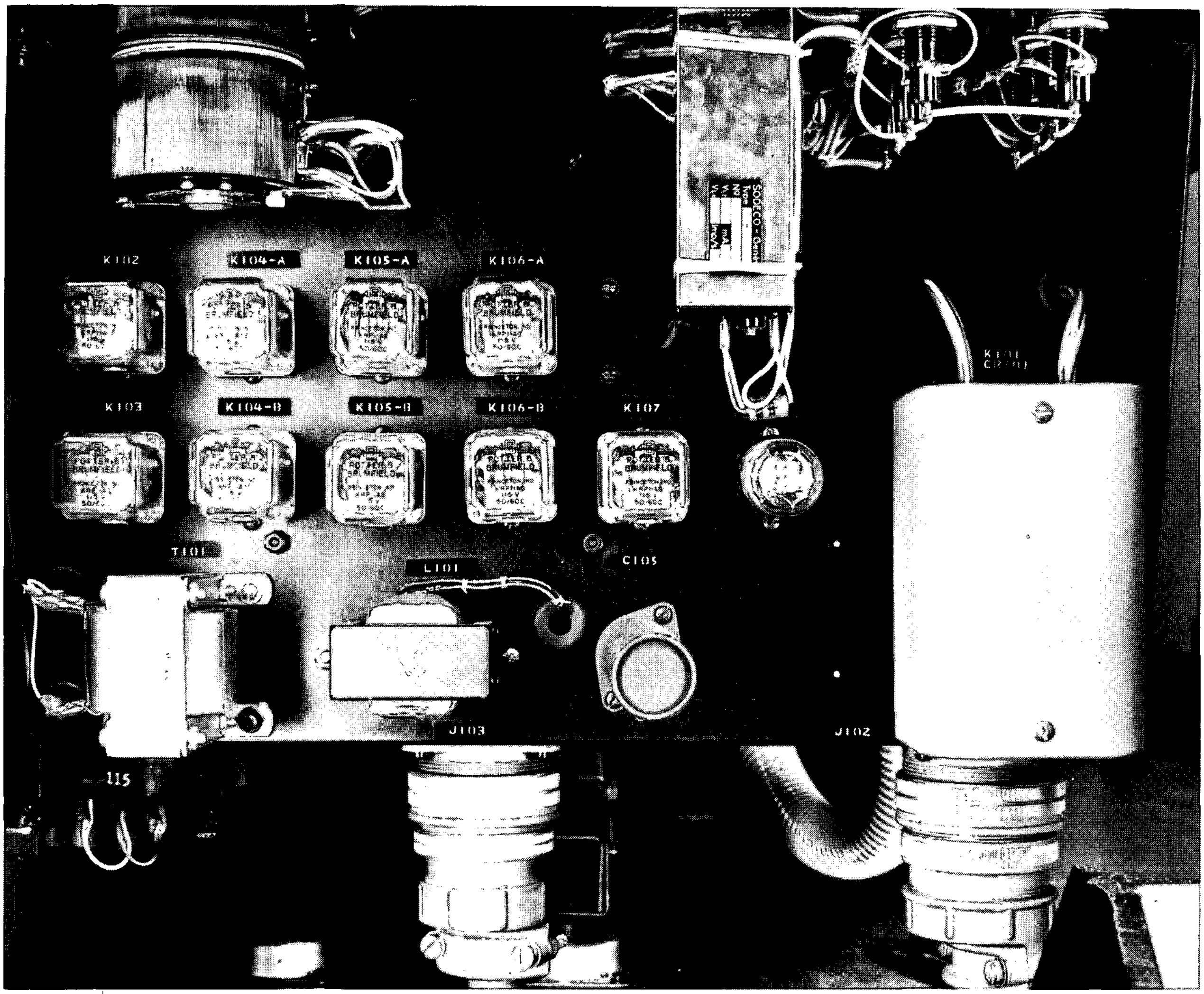

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Fig. 6-31 — Front view of control chassis

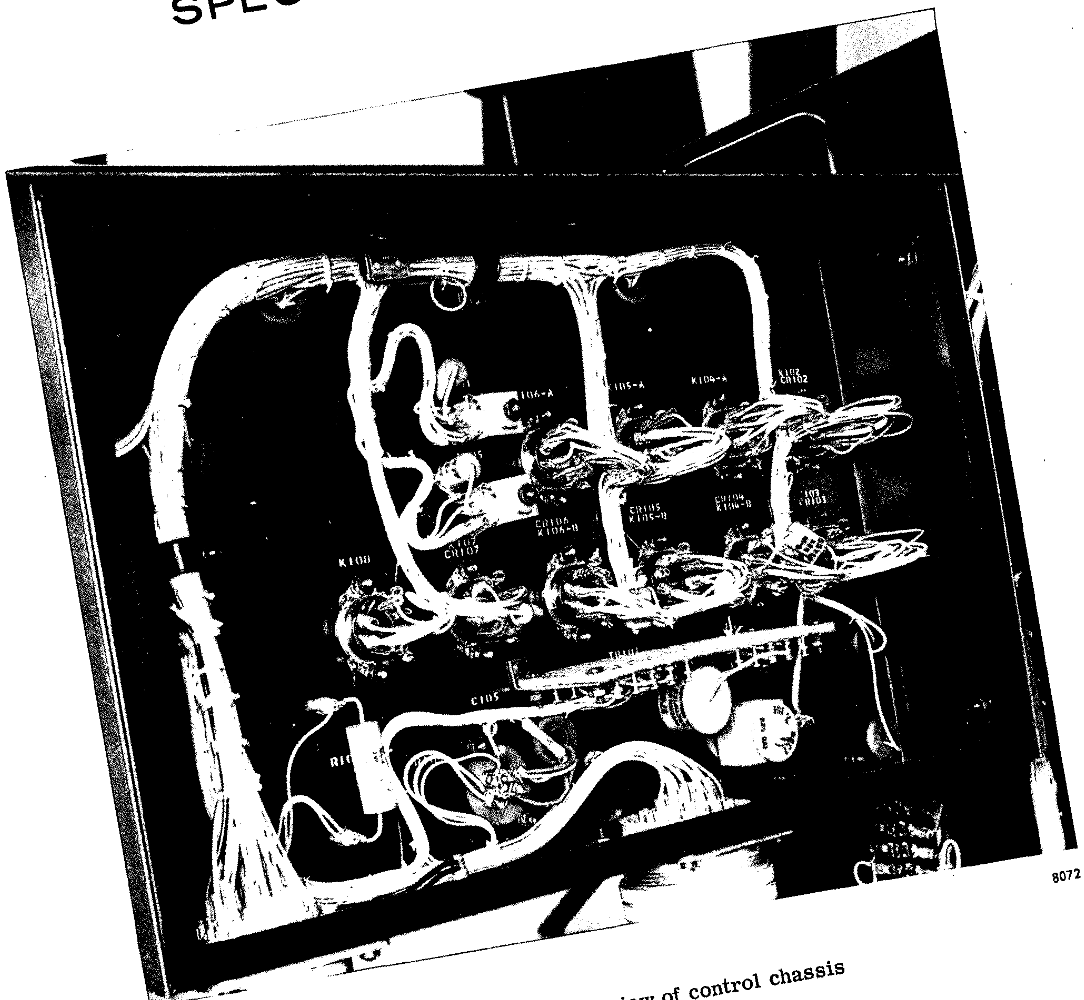


Fig. 6-32 — Rear view of control chassis

7. ALIGNMENT AND CALIBRATION TECHNIQUES

This section is intended as a guide for the alignment and testing of the Gamma I Rectifying Printers. The techniques developed here are by no means the only possible methods, and improvements will suggest themselves. However, whatever techniques evolve from this outline, the need for patience and careful, methodical alignment and test procedures will remain constant. This is stressed throughout the section and is a prime requirement for the ultimate success of the rectifier.

7.1 INITIAL EQUIPMENT ALIGNMENT

This section establishes a procedure for setting the easel and baseplate parallel to each other on a common centerline.

7.1.1 Equipment

The following alignment equipment is required:

25X1
1. Two [redacted] T-2 theodolites or equivalent, with autocollimating eyepieces and power pack
2. One theodolite stand, with vertical and lateral motion capability
3. One first surface mirror, approximately 6 to 8 inches long, 2 to 4 inches wide, and at least 1/4 inch thick. The mirror should be accurately plane parallel to less than 30 arc-seconds. Selected Liberty twin ground mirror stock is satisfactory
4. One precision square, with a 12-inch (or longer) straightedge.

7.1.2 Theodolite Positioning

Theodolite positioning is accomplished as follows:

1. Mount theodolite 1 on the adjustable stand, and position it as shown in Fig. 7-1 about 4 to 5 feet behind the easel and roughly in line with the three frame reference pins, P_1, P_2, and P_3.

2. Rotate the stand so that the lateral slide is reasonably parallel with the easel.

3. Lower the theodolite stand off its casters and onto its three leveling jacks to help prevent accidental moving of the stand.

4. Raise the vertical column of the stand sufficiently high so that by traversing the theodolite in a vertical plane all three reference pins can be sighted successively.

5. The theodolite should be positioned on the stand with two of its leveling pads (A and B) in a line perpendicular to the easel. (Fig. 7-2). The third pad, C, can then be used to tilt the theodolite into the same vertical plane as the rectifier, and eliminates the necessity for precision leveling of either the rectifier or the theodolite.

25X1

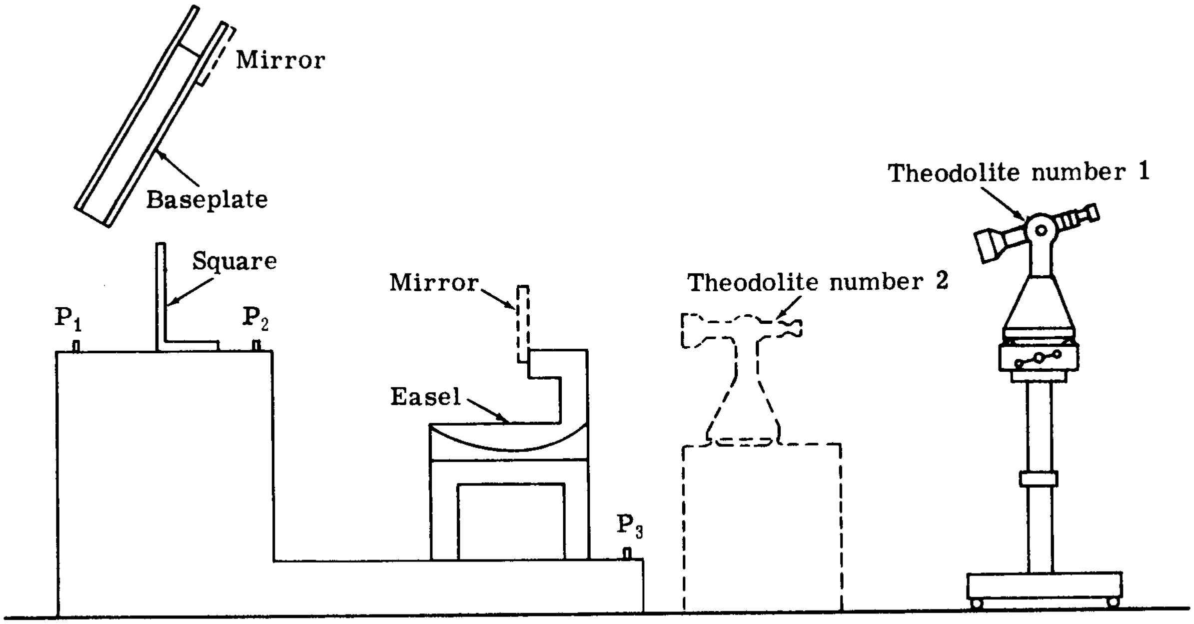


Fig. 7-1 — Baseplate and easel assembly

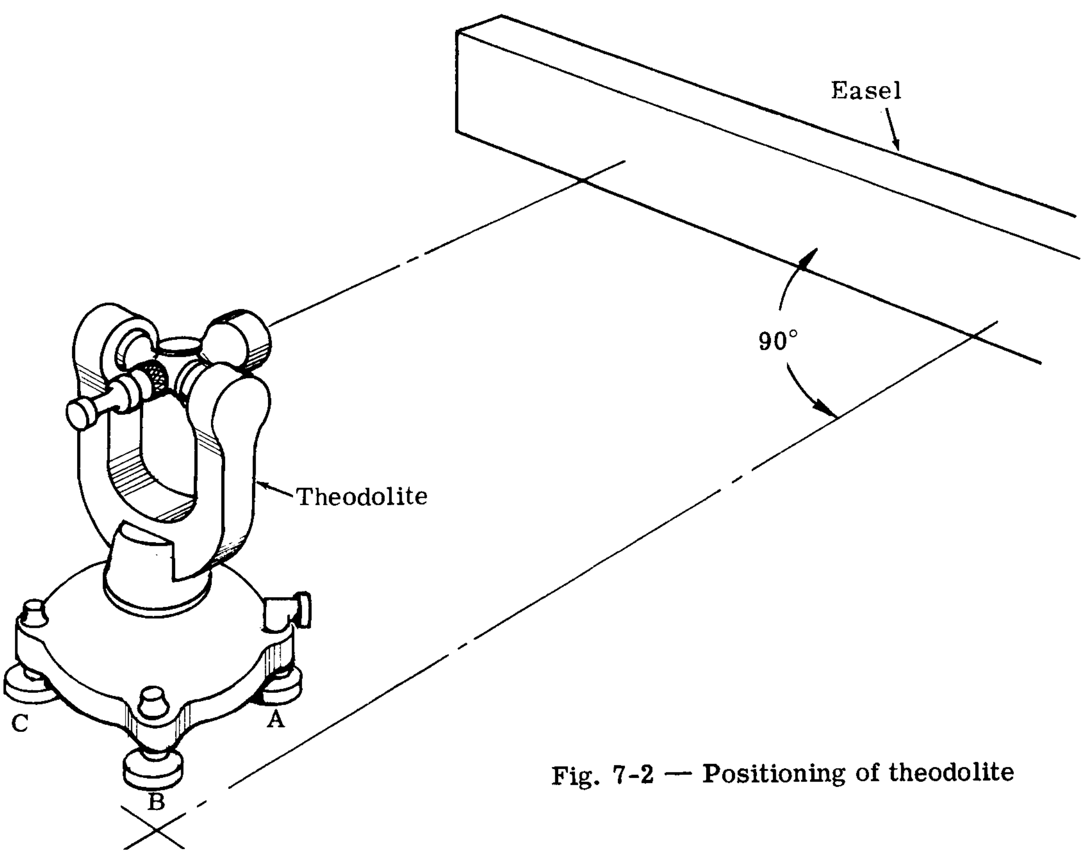


Fig. 7-2 — Positioning of theodolite

6. The three reference pins, P_1, P_2, and P_3, lie in a plane which passes through the center of the rectifier. To ensure that this plane passes vertically through the unit, set up the square on the mirror mounting plate between P_1 and P_2 and just to one side of the centerline.

7. All three pins should be completely visible in the theodolite, and the square's straight edge should be seen just slightly displaced laterally from the pins.

8. Focus theodolite 1 on the straight edge and traverse between the top and bottom along one edge. If the image of the straight edge does not remain at a constant distance from the crosshair, adjust leveling pad C until the theodolite traverses parallel to the straight edge.

9. Sight alternately on P_1 and P_3. Translate and/or rotate the theodolite horizontally until P_3 is accurately centered about the crosshair.

10. Resight on P_1 and observe its position relative to the crosshair. Note that images are inverted and reversed left and right. If the image of P_1 appears too far to the left in the theodolite, it is really too far to the right of the theodolite axis and P_3 (Fig. 7-3). In this case, sight once again on P_3. Move the theodolite to the left so that the image of the left edge of P_3 is approximately centered at the crosshair. Then rotate the theodolite in a clockwise direction so that P_3 is again recentered.

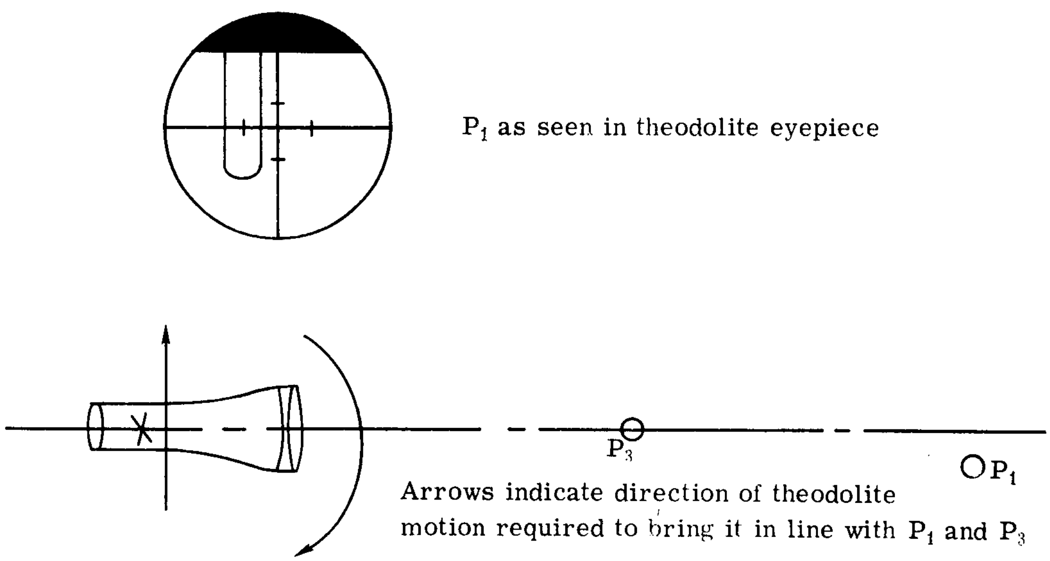


Fig. 7-3 — Position adjustment of theodolite

11. Refocus on P_1 and determine what further improvement is necessary. By alternately sighting on P_1 and P_3, rotating, and translating, the theodolite can be brought accurately into line with the pins. During this operation the vertical alignment with respect to the straight edge of the square must be constantly checked and corrected where necessary.

12. It should be noted that alignment with the pins is facilitated if one pin, such as P_3, is chosen as a reference. By first translating the theodolite so that the image is decentered, and then rotating so that this pin appears to be accurately centered again, it is possible to obtain fairly rapid alignment of the theodolite to the pins.

13. Check the alignment of P_2 with the other two pins, and with the vertical straight edge.

Considerable patience should be exercised in this setup procedure, for this is the starting point on which the successful alignment of the baseplate and easel depends. Once the theodolite is established accurately in line with the pins and traversing in a plane perpendicular to the mirror mounting plate (i.e., parallel to the square's straight edge), the alignment of the easel and baseplate can begin.

7.1.3 Easel Positioning

Easel positioning is accomplished by the following operations:

1. Insert a 1/4-inch-diameter rod in the centering hole of the easel reference pad.

2. Tilt the top of the easel downward, toward the theodolite, so that the rod can be seen in theodolite 1.

3. If the image of the rod appears to be decentered, move the entire easel support assembly laterally until the rod is centered.

4. Ensure that the easel is perpendicular to the vertical reference axis of the machine by traversing the theodolite past the two construction holes in the back of the easel. Both of these holes should be centered on the crosshair. If one is not, determine the direction of the error and shim under the appropriate side of the easel support feet.

5. Place the front surface of the mirror, described in Section 7.1.1, against the easel reference pad, with several inches of mirror surface visible above the top of the pad.

6. Adjust the vertical tilt of the easel and vertical traverse of the theodolite so that the theodolite axis is approximately perpendicular to the mirror on the easel reference pad.

7. With the lamp in the theodolite eyepiece, turn on the power pack and focus the theodolite at infinity for autocollimation. By proper adjustment of the vertical tilts of the theodolite and easel, bring the horizontal lines of the crosshair and its reflected image approximately into coincidence.

NOTE

Do not rotate the theodolite horizontally, because this will destroy the original centering alignment.

8. If the image of the vertical line of the crosshair is displaced to the left or right of the crosshair itself, this indicates that the easel is not perpendicular to the theodolite axis. It should be noted that only this left-right error need be corrected, since the up-down error is corrected by tilting easel and theodolite as desired.

9. Determine the horizontal direction the easel must be rotated by lifting an edge of the mirror which drives the image of the crosshair toward center. Rotate the easel in the same direction, and by the same amount.

10. Check the centering by repeating steps 1 through 4.

11. Repeat the autocollimation procedure alternately with the centering procedure until the easel is accurately centered with the reference pins and theodolite, and accurately at right angles to the theodolite.

12. With the easel accurately centered and perpendicular to theodolite 1, setup theodolite 2 on a stand or firm box between the easel and theodolite 1.

13. With the easel upright, the axis of theodolite 2 should be approximately level and 1 to 4 inches above the top of the easel.

14. Autocollimate theodolite 2 from the mirror on the easel reference pad by rotating theodolite 2 as required in both vertical and horizontal planes. The easel may also be rotated vertically if necessary. The autocollimation of theodolite 2 merely makes its axis parallel with that of theodolite 1, and is used later in setting the vertical projected plane of the baseplate parallel to that of the easel. It is not necessary to center theodolite 2, except as required to achieve autocollimation in the mirror. However, theodolite 2 must traverse in a vertical plane parallel to the straight edge of the precision square. Two of its feet should be perpendicular to the easel (similar to theodolite 1, as in Fig. 7-2). Alternately autocollimate off the mirror on the reference pad and tilt theodolite 2 so that it traverses parallel to the straight edge.

It should become apparent from Fig. 7-1 that theodolite 2 is necessary only because of geometry restrictions. It is not practical to use theodolite 1 for both centering and parallelism tests because of the forward angle of tilt of the baseplate and the extremely long mirror which would be required in the plane of the baseplate. This problem will be further explained below.

With both theodolites appropriately aligned, number 1 can now be used for all remaining centering checks and number 2 can be used to bring the baseplate parallel to the easel.

7.1.4 Baseplate Positioning

The baseplate is positioned as follows:

1. Set the baseplate assembly in position so that the vertical scribed line on the front of the plate appears to be roughly centered when viewed with theodolite 1.
2. Place the alignment mirror near the top of the plate, and flat against it. Make sure that no burrs or dirt are on the plate to cause the mirror to rock.
3. After having checked the autocollimation alignment of theodolite 2 with the easel, rotate theodolite 2 vertically (without rotating it horizontally) and autocollimate it with the mirror on the baseplate.
4. As was the case with the easel, only left and right errors of the reflected crosshair image are of any significance. If such an error exists, rotate the entire baseplate until the vertical lines of the crosshair and its image coincide.
5. Now check the centering of the scribed line with theodolite 1. Traverse along the length of the line, making sure that the line appears to fall on the crosshair during the entire traverse.
6. If the image of the scribed line is displaced laterally from the crosshair but remains a constant distance from it during traverse, a lateral repositioning of the entire baseplate is all that is required. The amount of error can be determined by placing a scale over the scribed line and by observing the magnitude of the error in the theodolite.
7. If the scribed line appears to track off during traverse, i.e., appears to be tilted, and if autocollimation indicates that the vertically projected plane of the crossplate is parallel to the easel, the entire baseplate must be shimmed on the appropriate side.

8. Again, alternately check centration and vertical alignment of the baseplate with theodolite 1, and parallelism of the baseplate to the easel reference pad with theodolite 2.
9. Set the mirror mounting plate in position such that its vertical pin lies along the line established by the three reference pins.

At all times, secondary checks should be used to avoid gross accidental errors. Dirt or burrs on either the easel reference pad or the baseplate can introduce errors in the parallelism tests, which could be serious if not detected. As a reasonably accurate check on parallelism, determine the distance with a tape measure from one corner of the baseplate to the easel channel and see if it is the same as the distance from the corresponding opposite corner to the easel channel.

If sufficient care was exercised to this point, the easel and baseplate should now be accurately parallel to each other and on a common center. Alignment of the rest of the system can now be undertaken. Theodolite 2 can be removed but theodolite 1 must be left in position for the initial centering of the scan arm and roller assembly, as described below.

7.2 ALIGNMENT OF PROJECTION SYSTEM

This section describes the steps for the alignment of the film guide rollers, lens, main mirror, easel, slit, and illumination system.

7.2.1 Equipment

The equipment required for the alignment of the projection system is as follows:

1. Squaring-on eyepiece and flashlight (Fig. 7-4)

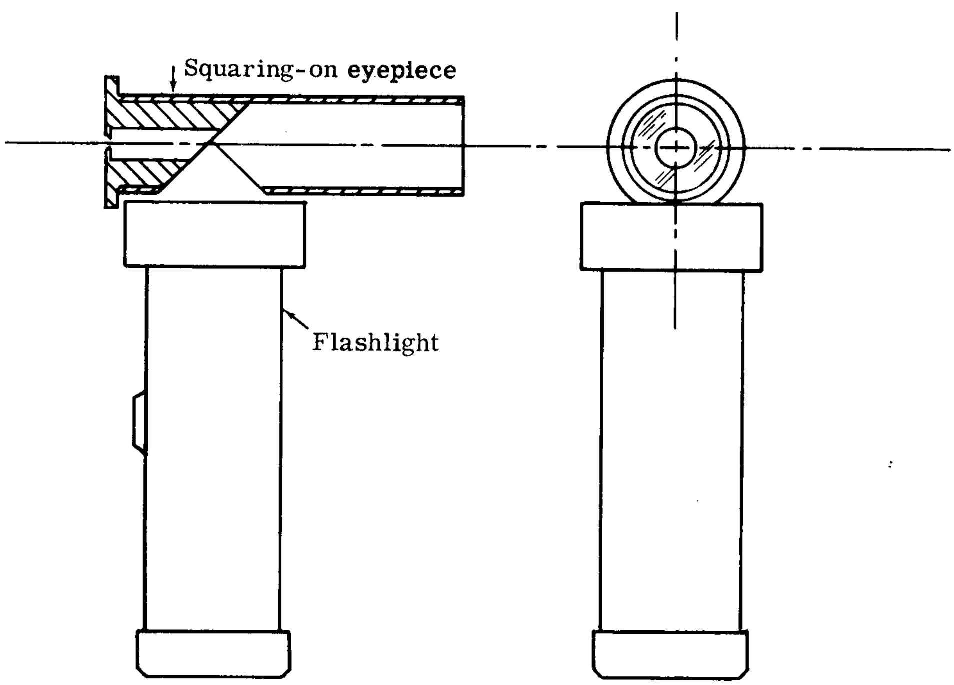


Fig. 7-4 — Squaring-on eyepiece and flashlight

2. Roller centering gauge (Fig. 7-5)
3. Two 2- by 2-inch beam splitters (microscope cover slides with a metallic or dielectric coating will work well)
4. A mirror, such as described in Section 7.1.1
5. A bright light source, such as a 100- to 150-watt trouble light
6. One glass or gelatin color filter, green or red, at least 1/2 by 1/2 inch.

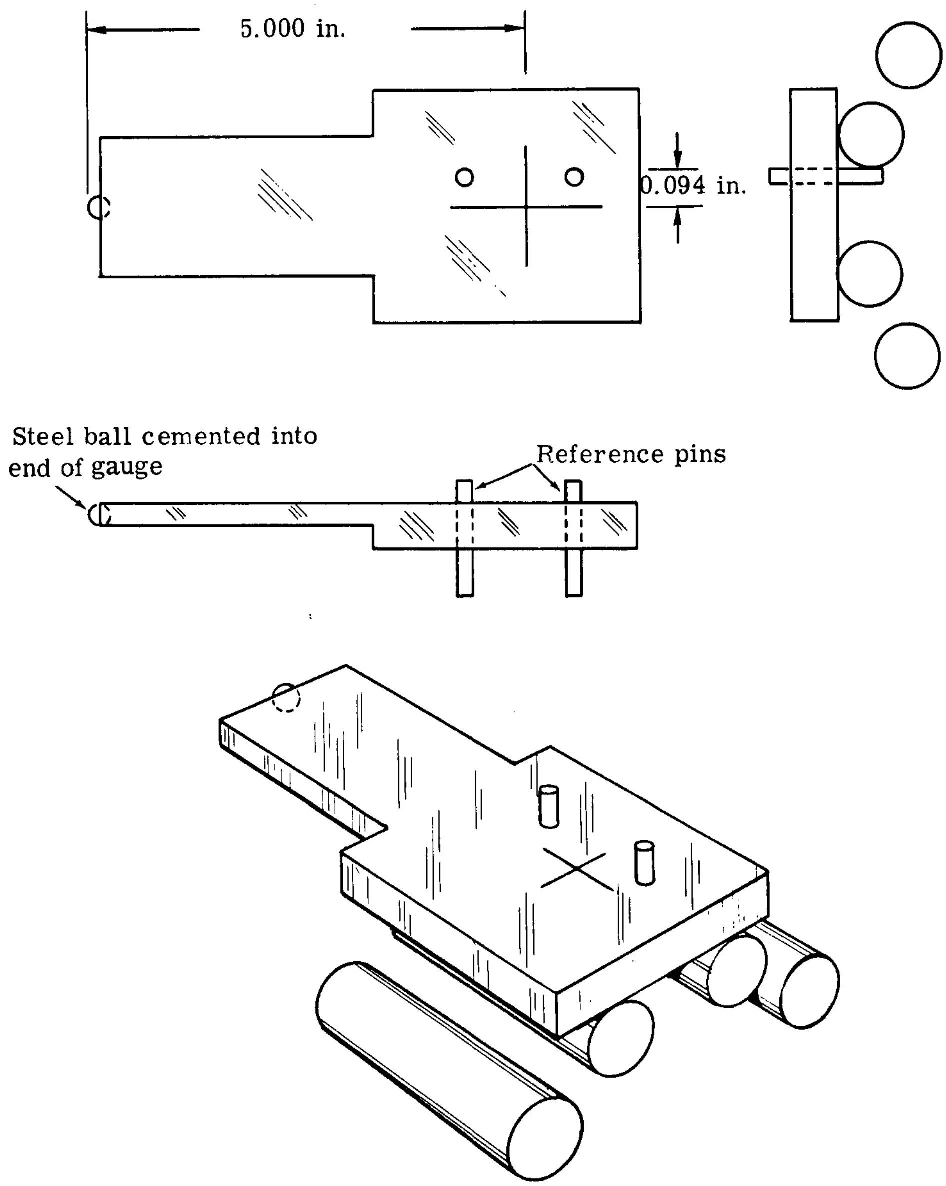


Fig. 7-5 — Roller centering gauge

7.2.2 Scan Roller Assembly Alignment

The scan roller assembly is aligned as follows:

1. Remove the condenser assembly, slit, and projection lamp from the lamp house.

2. Prior to the installation of the roller assembly, insert a 1/4-inch-diameter rod in the alignment hole of the scan arm.

3. Rotate the scan arm until the rod is seen to be accurately centered in theodolite 1. Clamp the scan arm rigidly at this position. This puts the scan arm on the vertical centerline of the unit.

4. Remove the rod and install the roller assembly. The rollers should be about 0.006 inch higher than the guide rails with no slope or tilt with respect to the rails.

5. Centering of the rollers can be facilitated with the aid of a centering gauge such as the one shown in Fig. 7-5. The distance of the scribed line from the two pins is equal to half the separation of the vertical tangents of the two center rollers. This distance from the outside tangent of the pins to the scribed line is nominally 0.094 inch, but the roller separation for each rectifier should be checked. If the roller separation varies from unit to unit by more than about ±0.002 inch, new scribed lines or completely new gauges should probably be used to maintain centering accuracy.

6. Position the roller assembly laterally until the scribed line is centered in the theodolite. The pins of the gauge must be kept in contact with the reference roller, and the gauge must be held flat against the top of the rollers.

7. Alternately check the height and the centering of the rollers. Note that the scribed line should lie in the plane of traverse of theodolite 1. If it appears tilted, the roller assembly is probably skewed with respect to the scan arm and should be corrected by shimming under the assembly.

The preceding steps should set the scan arm at nadir with the rollers accurately aligned and centered.

7.2.3 Projection Lens Alignment

The following steps establish the optical axis of the lens perpendicular to the input film, i.e., to the tangent plane across the two middle rollers:

1. Place a beam splitter on the two middle scan rollers. It should be taped in place but not otherwise restrained so that it will be flat in the plane tangent to the two rollers.
2. Tape a flat mirror across the machined end surface of the lens cell. This surface is finished accurately perpendicular to the optical axis. Make sure that the mirror is flat against the cell and is not cocked due to burrs and dirt.
3. Using the squaring-on eyepiece, illuminated with a flashlight or other suitable light source, sight through the top of the lamp house toward the roller assembly.
4. Align the eyepiece with the beam splitter on the rollers so that it is approximately centered with the rollers and is perpendicular to the beam splitter. The reflected image of the annulus (donut) of the eyepiece should appear to be directly in line with the eyepiece. This establishes a line perpendicular to the plane of the beam splitter.
5. With the projection lens and alignment mirror roughly squared with the rollers, sight through the beam splitter, between the rollers, and observe the position of the annulus reflected from

the mirror relative to that reflected from the beam splitter. The Scheimpflug vernier scale should read zero during this operation.

6. If the reflected image from the mirror on the lens is not accurately concentric with that of the beam splitter, there are two adjustments available to correct it:

   - If the error is in the scan direction, loosen the focus cam to rotate the lens in the scan direction without rotating the scan arm itself. As an aid in improving the alignment accuracy, try to center the eyepiece between the rollers. This way, the image reflected from the mirror will be symmetrically vignetted by the rollers and will appear to have flat sides. The important thing, however, is simply to get the two reflected images concentric
   - If the error is in the Scheimpflug direction, adjust the turnbuckle at the lens yoke, keeping the vernier scale at zero, until the image reflected from the mirror is aligned with the image from the beam splitter.

The two-coordinate motion provided by the focus cam and the turnbuckle are adequate to make the two reflected images accurately concentric. Again, it cannot be emphasized enough that considerable care and patience is required and that a constant series of checks and multiple observations or measurements should be made.

With the reflected images concentric, the lens axis should now be perpendicular to the input film plane. Observe and record the reading of the rack displacement dial indicator. This value should represent nadir or zero.

7.2.4 Rectifier Mirror Alignment

The folding mirror of the rectifier must be aligned such that the optical axis of the lens is projected to the center of the easel, and perpendicular to the easel. Alignment is accomplished by the following operations:

1. Remove the alignment mirror from the lens cell.

2. Set the easel to read zero on the vernier scale, and illuminate the centering hole in the easel pad from behind with a bright light.

3. It may be useful to put a colored filter (such as green) over the back of the centering hole. This will help differentiate the projected image of the hole from reflected images, as will be seen in subsequent steps.

4. Tape a beam splitter on the easel reference pad, approximately centered with the centering hole.

5. A beam splitter should also be in place on the rollers, as described in Section 7.2.3. Align the squaring-on eyepiece by autoreflection from the beam splitter as before.

6. Sight through the rollers and roller beam splitter. Tilt and move the main mirror toward or away from the easel until (1) the projected green image (or whatever color) from the centering hole is approximately centered between the rollers, and (2) an annular image reflected from the easel beam splitter is approximately concentric with that from the roller beam splitter.

7. Continue to tilt and rotate the mirror about its vertical and horizontal axes as required until the image from the easel beam splitter is accurately concentric with that of the roller beam splitter. The projected centering hole image should remain visible between the rollers.

8. Replace the roller beam splitter with the centering gauge.

NOTE

> Alignment could be facilitated here by evaporating a semireflective coating on the centering gauge, making the gauge serve a dual purpose for centering and perpendicularity tests. The top and bottom surface of the gauge must be accurately parallel, however. Errors due to lack of parallelism are minimized by putting the semireflecting coating on the bottom surface, i.e., in contact with the rollers.

9. The foot of the gauge should be held flat against the top base plate, and the pins should be against the reference roller. The horizontal cross line (i.e., the line parallel to the easel) is then located exactly 5.000 inches from the baseplate, crossing the optical axis. The vertical cross line should also pass through the optical axis, centered and parallel to the rollers.

10. Slide the mirror assembly back and forth until the projected image of the centering hole appears to be centered with the crosshair of the centering gauge.

11. Check perpendicularity to the easel by replacing the centering gauge with the beam splitter once again and observe the eyepiece images reflected from it and the easel beam splitter.

12. Tilt adjustments to correct for perpendicularity to the easel necessarily affect the location of the projected centering hole image. If mirror tilt is required, then it probably will also be necessary to translate the mirror as well to recenter the hole image.

13. Checks for centering must alternate with checks for perpendicularity by interchanging the centering gauge with the roller beam splitter. The advantages of combining the functions of the gauge and beam splitter will become obvious in the trial and error procedure of this stage.

14. Gradually tighten all the screws and lock nuts of the mirror adjustments. The projected and reflected images will be seen to wander somewhat during this operation, so considerable care must be exercised in maintaining alignment.

15. Remove the easel pad beam splitter, filter, and lamp. This completes the major portion of the optical alignment. The alignment of the flexible easel plate, the slit assembly, and the illumination system remain.

7.2.5 Flexible Easel Alignment

The flexible part of the easel should now be installed. Checks must be made to ensure that its center is parallel to the easel reference pad, i.e., perpendicular to the optical axis. It must also be determined that one end of the easel is not higher than the other. Alignment is accomplished as follows:

1. Tape a mirror, or a beam splitter, on the center of the easel.

2. By autoreflection, make sure that the flexible easel plate is perpendicular to the optical axis. This is done in the same way that perpendicularity to the easel reference pad was established.

3. If an error exists, shim as required between the easel reference pad and the easel mounting holes. Make sure that the error is actually due to a lack of parallelism between easel and easel pad, and is not due to the position of the mirror on the slightly cylindrical surface of the flexible easel plate.

4. Install and turn on the projection lamp and fan, but do not install the condenser assembly and slit.

5. Place the centering gauge in position over the rollers. An image of the crosshair will be projected onto the easel.

6. The vertical line of the crosshair should be aligned with the set of vacuum holes which are spotted across the width of the easel plate at the center.

7. If the holes are displaced from the line image, loosen the easel plate and move it laterally as required. The limits of the mounting clearance holes may prevent exact coincidence of the line image with the vacuum holes. This is not particularly important, but it is convenient to use the vacuum holes later, if possible, to set the location of the slit. The line image must, however, be at least parallel to the vacuum holes, and at a measurable distance from the holes. This helps ensure that the easel is level, i.e., one end is not higher than the other, and facilitates slit alignment.

8. Recheck the perpendicularity of the optical axis to the easel by autoreflection, as before. The projection lamp, of course, has to be removed for this.

7.2.6 Illumination System Alignment

The lamp and condenser assembly must be properly aligned and focused to provide uniform illumination in the image plane. Alignment is accomplished by the following steps:

1. Stop the projection lens iris down to its smallest aperture, position 5.

2. Install the condenser assembly, slit, and lamp.

3. Open the slit to maximum aperture and turn on the lamp and fan.

4. The lamp filament image should be projected into the lens, and should be focused and centered at the iris.

5. The filament image can be focused through vertical motion of the entire lamp housing and/or the lamp. Centering can be achieved through sideways adjustment of the lamp and/or condenser assembly and/or lamp housing. However, the condenser assembly and housing should not be moved so much as to prevent alignment of the slit, since the slit assembly position is not entirely independent of the condenser position.

7.2.7 Slit Alignment

The slit can be accurately centered with, and set parallel to, the rollers by the following steps:

1. Turn on the projection lamp and fan.
2. Close the slit so that only a very narrow line is projected onto the easel.
3. Rotate and laterally move the slit assembly to superimpose the slit image with the vertical reference centerline at the easel. This line was previously established in step 7 of Section 7.2.5, and is either coincident with the vacuum holes or is at some known distance from the vacuum holes.

7.3 VISUAL CHECKS OF SYSTEM ALIGNMENT

Secondary checks are desirable to verify alignment of the system. The following steps and visual observations help establish this confidence.

7.3.1 Alignment of Optical Axis to Easel and Easel Focusing Ways

1. Thread a test film across the input rails. This test film has a scribed or photographic line located 5.000 inches from the top baseplate and parallel to the long dimension of the film.

2. Narrow the slit down to about 1/2 millimeter, or smaller.

3. Turn on the lamp and fan. The image at the easel, produced by the vertical slit and horizontal scribed line, will be a small point or patch of light which should be exactly at the center of the easel.

4. Turn the easel focusing lead screw so that the easel travels its full range. Observe whether the point of light remains accurately at the center of the easel during this travel. It will, of course, grow in size as the easel moves in either direction from the plane of best focus, but it should stay centered.

5. If the image appears to track off, either vertically or horizontally, it could mean (1) an error in optical alignment, and the optical axis is not perpendicular to the easel, or (2) the focusing ways are not parallel to the optical axis, or perpendicular to the easel.

6. Reset the easel to a position where the image appears to be in good focus. Now back the easel out of this plane by only the amount required for the maximum easel tilt, a distance of about 3/4 inch. If apparent image motion is restricted to less than about 0.005 inch, photogrammetric geometry will probably be satisfactory. It should be noted that an image displacement of only this amount, however, represents an angular misalignment of more than 20 arc-minutes. It should be possible, through careful and systematic testing, to align the unit nearer a value of 1 arc-minute.

7. If, over the 3/4-inch range of travel required, the image movement is excessive, recheck the possible sources suggested above in step 5.

7.3.2 Alignment of Optical Axis With Easel Rotational Axis

This alignment is accomplished by the following steps:

1. Reset the easel to the plane of best visual focus.
2. Tilt the easel through its required range, and determine whether the image appears to remain stationary.
3. Any image motion would indicate that the image is not intersecting the rotational axis of the easel.

NOTE

If there are apparent image positioning errors, check also the location of the scribed line on the test film. Since there is an image magnification of about 1.9×, errors in location of the input reference marks will be correspondingly magnified at the easel.

7.3.3 Double Slit Test for System Alignment

The double slit test is accomplished by the following steps:

1. Cut or inscribe two slits approximately 1 inch long at right angles to the length of opaque 70 millimeter film. The separation between slits need not be accurately known, but should be about 6 to 10 inches apart.

2. Insert a suitable length of exposed but undeveloped film in the easel, and hold it in place with the vacuum.

3. With the easel and lens set a zero tilt, center one slit (in the input station) accurately at nadir and mark its image on the output film. The easel should be set to provide a sharp visual focus of the slit image.

4. Without distrubing the input film, rotate the scan arm until the second slit is projected onto the film at the easel. Focus the lens and mark the position of the slit image.

5. Reset the scan arm and lens to nadir. Transport the input film until the second slit is accurately at nadir.

6. Rotate the scan arm in the opposite direction to project the image of the slit which originally was at nadir but is now at some scan angle, α. Again, focus the lens and mark the position of the image.

7. Remove the film from the easel and check for symmetry by (1) returning the scan arm to nadir, (2) rotating the film 180 degrees end for end and replacing the film on the easel (accurately align the center of the film with the projected nadir image), and (3) repeat steps 3 through 6 above, and mark the position of the projected images on the film. The images should be coincident or symmetrical.

This test is a fairly sensitive check of the overall system alignment, including rotation of the scan arm and lens. Note that slits are used here instead of pinholes (which provide an equally valid test) only because it might be slightly easier to scribe two lines at right angles to the film than to get the two pinholes on a line accurately parallel to the edge of the film.

A lack of symmetry could indicate a misalignment of the optical system, a horizontally tilted easel, or misalignment between the scanning axis and the optical axis. The latter is probably the most difficult to correct and may require a very thorough reexamination of the entire optical alignment.

An accuracy check for system alignment is performed as follows:

1. Calibrate the scribed displacement of the double slit input test film.
2. Calculate the rectified position of the outboard slit (considering the inboard slit coincident with the rectifier centerline) for tilt setting of 15 degrees and altitude settings of minimum, nominal, and maximum.
3. After the performance of the symmetry test, measure the rectified displacement at the slits from center and compare with the calculated positions. The actual displacements should be within 0.010 inch at the calculated positions.

7.4 PHOTOGRAPHIC VERIFICATION OF ALIGNMENT

Photographic tests to determine planes of best focus, exposure settings, and symmetry of scan angle should be made prior to the start of focus cam calibration.

7.4.1 Alignment at Nadir

Alignment at nadir is accomplished by the following steps:

1. Set the easel and lens tilt angles to zero. Set the scan arm and lens at nadir. Set the lens aperture at 1 (maximum opening).
2. Insert a high resolution negative target array (clear lines on black background) in the input station.
3. Connect the projection lamp to a photographic exposure control timer.
4. With the timer at focus, transport the test film until the smallest targets are located at the center of the slit image on the easel. Narrow the slit for accurate target location, then open it for maximum information in data collection.
5. Translate the easel to the plane of best visual focus. A 35× to 40× microscope will help establish this plane. Note that even with the lens wide open, the depth of focus is on the order of ±0.010 inch, and increases to about ±0.040 inch at the design aperture, 3.
6. Run a series of exposures on type 5427 or 8430 film. A typical exposure level with 5427 film is 0.5 second with a 0.6 neutral density filter inserted under the slit.
7. Adequate film processing for initial testing includes developing in D-19 at 70 degrees for 4 minutes, a short rinse, and 1 ½ to 2 minutes in Rapid Fix. Final test films should be carefully processed for high resolution, low grain and fog, minimum scratches, proper fixing and washing, etc.
8. After a satisfactory exposure level has been obtained, make a through-focus run by translating the easel at least ±0.050 inch (depending on how well the photographic focus appeared to correspond with the visual focus) in 0.005-inch increments. Evaluate the test film and determine the best focal setting.
9. Make at least two more photographic tests at the "best focus" setting to check repeatability.
10. Determine whether the lens is actually being used on axis by loosening the focus cam from the scan arm. Rotate the lens first one way in 0.010-inch increments to a total rack displacement of about 0.100 inch, and then an equal amount in the other direction. The scan arm itself should remain at nadir.
11. Photographic tests at these rack settings should indicate a gradual but symmetrical defocusing of the image. A marked lack of symmetry would indicate that the nadir position of the lens should be reevaluated. This could include a check of the lateral location of the trunnion axis.

7.4.2 Extraaxial Symmetry Tests

Once it has been established that the nadir position of the lens is correct, image symmetry with respect to scan angle can be tested.

1. Set the scan arm at some large, but arbitrary, position of, say, +30 degrees. This is in a region where small changes in the field angle of the lens make rapid changes in the focal plane of the images; therefore, this region is more sensitive than the small scan angle region.
2. Easel curvature is arbitrary, but should be symmetrical.

3. Align the targets in the slit, as was done at nadir.
4. Adjust the focus cam to put the images in good visual focus. Then make a focus test photographically by rotating the cam such that the rack is displaced ±0.010 inch from best visual focus in 0.001-inch increments.

NOTE

With a mirror taped at a slight angle between the film rails, it is possible to make cam position adjustments and to simultaneously observe the rack displacement readings on the dial indicator.

5. After the photographic tests have established the rack displacement for best focus at this scan angle, rotate the scan arm to the corresponding negative angle of, say, −30 degrees. Angular position should be measured carefully. It can be done using the linear scale attached to the baseplate arc.
6. Check visual focus at the negative scan angle. It should occur at a nearly equal but opposite rack displacement obtained at the positive scan angle.
7. Repeat the incremental cam positions and photographic tests described in step 4. Analyze the film to determine the plane of best focus across the entire width of film.
8. At this scan angle there should not be a difference of rack displacement of more than about 0.004 inch. An error greater than this should be a cause of concern in the alignment of the easel with respect to the rest of the optical system, and should be further checked.

7.5 FOCUS CAM CALIBRATION

For every angular position of the scan arm, image focus at the easel is dependent on the correct field angle of the lens. The lens rotates with the scan arm, but at a different rate, to maintain focus throughout the field. This differential rate is established by the profile of the focus cam, linking scan angle with lens angle.

Complicating the cam design is the fact that for every set of input parameters such as camera altitude and tilt, a slightly different cam profile is required to maintain focus in the rectifier. This gives rise to a complex three-dimensional cam shape whose dimensions, which in theory can be calculated mathematically, must be determined empirically.

7.5.1 Alignment at Nadir for Tilted Easel and Lens, and Determination of Δd_0

For a given altitude and primary tilt angle of the camera, there exists a corresponding rectifier easel tilt angle, t', lens tilt angle (Scheimpflug angle, ϕ), easel focal position, Δd_0, and easel curvature which will produce the desired image geometry and focus. These are determined by the following procedure:

1. Pick a nominal set of camera parameters, such as a 15-degree primary tilt angle at maximum altitude.
2. From the data sheets, determine the corresponding rectifier settings for t', Δd_0, ϕ, and curvature, and make the appropriate settings on the rectifier.

3. It will be noted that for all tilt angles other than zero, the value for d_0 (the distance from the point of rotation of the lens to the easel, measured at nadir) will always be greater than at zero tilt.

4. With the proper settings applied to the rectifier, examine the image across the field visually. The scan arm and lens should be at nadir, and the lens should be wide open (position 1) for minimum depth of focus.

5. If the visual focus appears good across the field at nadir, run a photographic through-focus test. This test, which should go at least ±0.050 inch in 0.005-inch increments, will determine: (1) the plane of best focus, and (2) whether this image plane is actually parallel to the easel.

6. The direction and amount of mismatch between the two planes, if such an error exists, can be readily determined from the photographic tests. It should be possible to make a fairly accurate calculation as to the angular error, and to correct the easel tilt accordingly.

7. Repeat the through focus tests, as required, with small incremental changes made in the easel tilt until a good match is made.

8. Observe and record the easel focal setting at the plane of best focus. This determines Δd_0 for these parameters and is needed as a part of the empirical data sheet.

7.5.2 Determination of Cam Setting for Corresponding Scan Angles

Rack displacement setting should be determined in at least 5-degree increments of scan angle through the entire scan angle range of ±40 degrees. This setting is determined by the following procedure:

1. Stop the lens down to the design aperture, 3. This minimizes astigmatism at large field angles and helps establish the proper rack displacement.

2. With the easel and lens settings used above, rotate the scan arm and set it accurately at + 5 degrees.

3. Adjust the focus cam as required to produce a good visual focus.

4. The total rack displacement required for a thorough test at this scan angle can be determined by observing when the image starts to go out of focus for cam rotational positions on each side of best focus. A relatively large rack displacement will be required at small scan angles to cause much of a change in focus. At the low scan angles, it may be necessary to displace the rack as much as ±0.015 inch in 0.001-inch or 0.002-inch increments. As a rough guide, it will be noted that for every 5 degrees of scan angle, the rack displacement will increase (or decrease, depending on whether the scan angle is positive or negative) by about 0.030 inch. This is only an approximation, but is helpful in initially setting the cam position.

5. After a range of rack displacements has been determined visually, make a photographic test through this range.

6. Determine from the photograph the optimum rack position for best focus across the field, and record this data.

7. Repeat the above steps for every 5-degree incremental scan angle. It will be noted that the focal setting becomes much more critical as the scan angle increases. It is also easier to determine exactly what rack displacement is best.

8. When all of the appropriate data has been collected, it is possible to plot a curve reflecting scan angle versus rack displacement. This should be a nearly smooth curve, generally S shaped, and nearly symmetrical.

9. Repeat the steps of Section 7.5.1 and steps 1 through 8 above for the same primary tilt angle but minimum and mean altitude settings. Again, a set of curves having the same general shape as the first curve is expected.

10. As an aid in determining the empirical points, it may be valuable to first plot all the theoretical data. This plot can be used to help locate the proper range of rack displacements to try at a given scan angle under a given set of input parameters.

It should be pointed out that apart from this sort of guide there does not appear to be any reliable shortcut in the data collection. It is generally faster in the long run to collect too much data than to try to reduce the number of points taken. All too often the result is that much of the experiment has to be repeated because of a lack of adequate coverage.

Experience with the rectifier will, of course, point out improved and perhaps faster methods for data collection. At any rate, a careful and methodical system for data collection and analysis must be maintained to maximize the inherent capability of the instrument.

Once the cam has been cut and installed in the rectifier, dynamic tests can begin. If resolution figures are lower than expected, a recheck of the cam profile should be made, along with rectifier settings. Image motion is not expected to be a problem with this lens because of its low distortion characteristics.

In general, the vertical or tangential lines of the resolution targets should probably be slightly favored for best focus to help compensate for any residual image motion which might exist.

Tests for exposure banding, with no film in the input aperture, should be made. Fog tests and sensitometry tests should also be made.

7.6 CAM CALIBRATION—LENS FOCUS

Data obtained from photographic results has indicated the sensitivity of the field angle—distance relationships in the mechanical and optical functions of the Gamma I Rectifying Printer. The general conclusion that can be drawn from the test results is that although the depth of focus at maximum scan angle is more than 2×, the zero scan focus depth (the sensitivity to focus angle at maximum) is many times greater than on or near the lens axis. A "paper" analysis of the lens sensitivity substantiated the recorded data. Fig. 7-6 shows the relationships for the approximations used in the paper analysis.

The total focusing tilt angle is found by the relationship

$$\cos \eta = \cos \gamma \cos \phi$$

where η = focusing tilt angle
γ = Angle between the lens centerline and the slit
ϕ = Scheimpflug angle

Since ϕ is held constant for any single easel tilt, the change in η ($\Delta\eta$) equals the change in γ ($\Delta\gamma$).

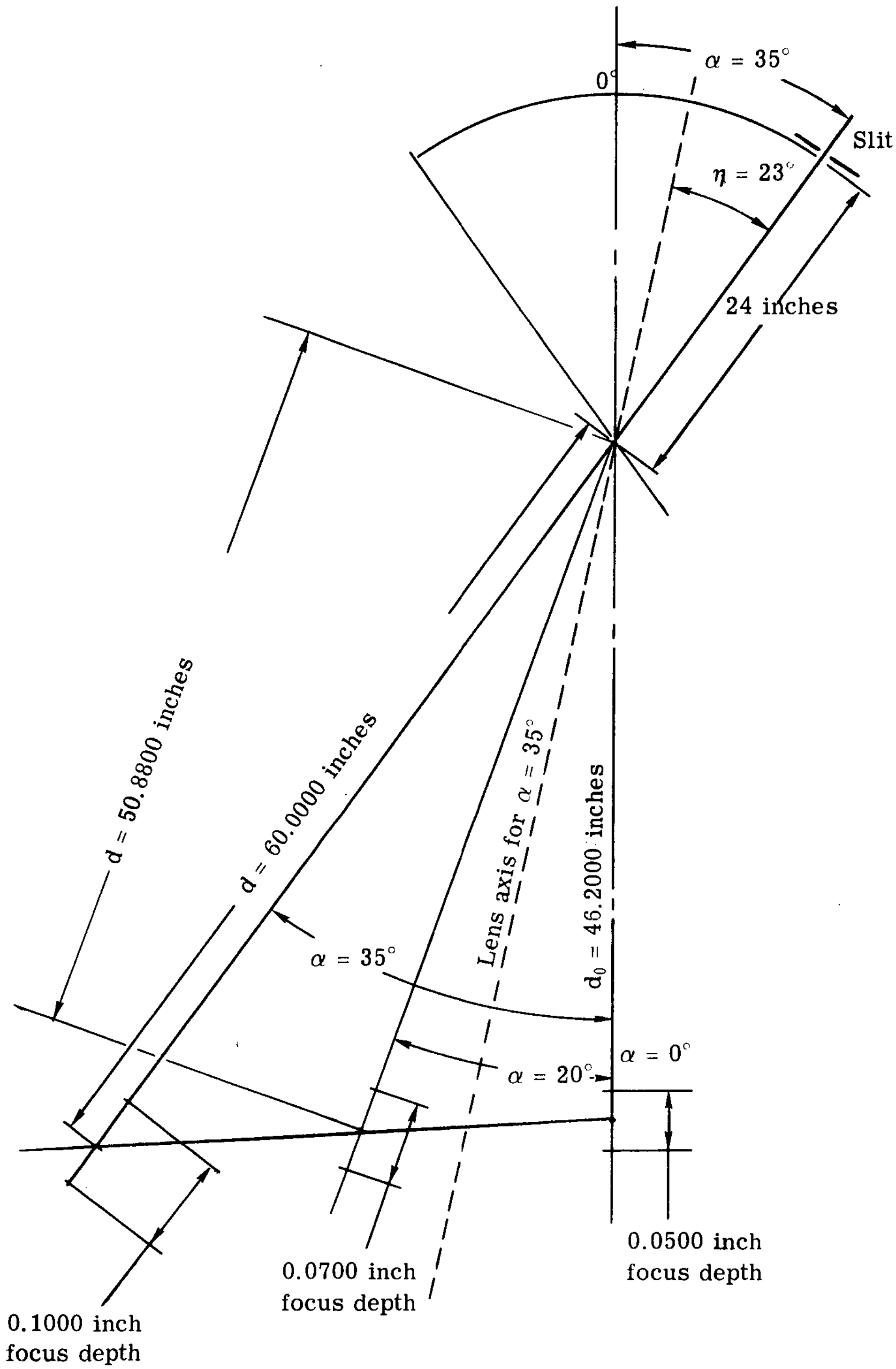


Fig. 7-6 — Approximation relationship used in "paper" analysis

With known values for rectifier focal length, f, camera focal length and also rectifier image conjugate, F, and rectifier object conjugate, d, the total focusing tilt angle, η, can be computed by the relationship (refer to Table 7-1).

$$\cos \eta = f(F+d)/Fd$$

Table 7-1 — Lens Focus Summary Sheet

Focal length of rectifier lens, F, inches	15.8000	15.8000	15.8000
Input radius, F, inches	24.0000	24.0000	24.0000
Scan angle, α, degrees	35	20	0
Focus angle, η	22° 49' 44.5"	14° 20' 03"	θ constant
Distance, d, inches (lens center to point of best focus)	60.0000	50.8800	46.2000
Depth of focus, inches (see Fig. 7-7)	0.1000 or ±0.0500 from d	0.0700 or ±0.0350 from d	0.0500 or ±0.0250 from d
Δd, inches $\Delta\eta$, arc-seconds $\Delta\eta = \Delta\gamma$ where θ is constant, inches per arc-minute η	0.0010 2.5 or 0.0240	0.0010 4 or 0.0150	Insensitive
Δd, inches $\Delta\eta$, arc-minutes	0.0500 2	0.0350 3	

This is a theoretical solution for a perfect lens system. Optical characteristics of a chosen lens system would require that angle, η, be determined by empirical data.

For $\alpha = 35°$

$$\cos \eta = \frac{f(F + d)}{Fd}$$

$$= \frac{15.8000\ (24 + 60.0000)}{24 \times 60.0000}$$

$$= \frac{1327.2000}{1440.0000} = 0.921666$$

$$\eta = 22° \ 49' \ 44.5''$$

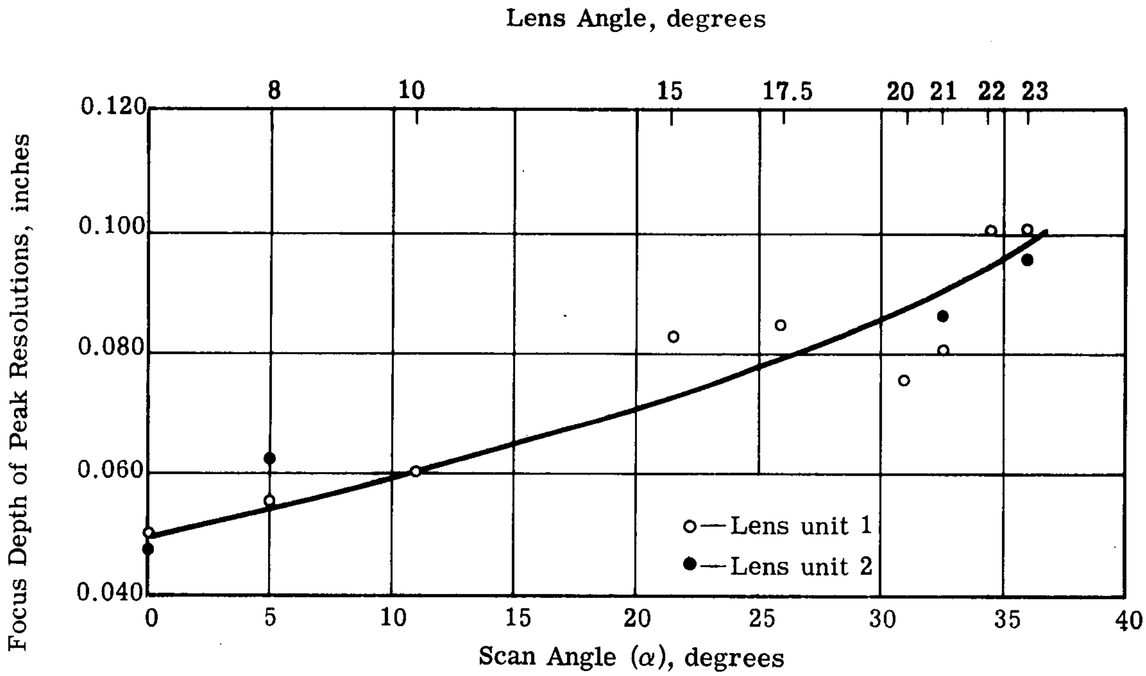


Fig. 7-7 — Focus depth versus scan and field angles (actual), based on photographic bench tests

For $\Delta d = 0.0010$ inch

$$\cos \eta = \frac{15.8000\ (24 + 60.0010)}{24 \times 60.0010}$$

$$= \frac{1327.2158}{1440.0240} = 0.921662$$

$$\eta = 22^\circ\ 49'\ 47.0''$$

For $\Delta d = 0.0500$ inch = (focus depth)/2

$$\cos \eta = \frac{15.8000\ (24 + 60.0500)}{24 \times 60.0500}$$

$$= \frac{1327.9900}{1441.2000} = 0.921447$$

$$\eta = 22^\circ\ 51'\ 41.0''$$

For $\alpha = 20°$

$$\cos \eta = \frac{15.8000\ (24 + 50.8800)}{24 \times 50.8800}$$

$$= \frac{1183.1040}{1221.1200} = 0.968868$$

$\eta = 14° \ 20' \ 03''$

For $\Delta d = 0.0010$ inch

$$\cos \eta = \frac{15.8000\ (24 + 50.8810)}{24 \times 50.8810}$$

$$= \frac{1183.1198}{1221.1440} = 0.968862$$

$\eta = 14° \ 20' \ 07''$

For $\Delta d = 0.0350$ inch = (focus depth)/2

$$\cos \eta = \frac{15.8000\ (24 + 50.9150)}{24 \times 50.9150}$$

$$= \frac{1183.6570}{1221.9600} = 0.968654$$

$\eta = 14° \ 23' \ 01''$

7.6.1 Focus Cam Calibration

The major mechanical component in the rectifier that ensures sharp focus is the focus cam. This component was originally intended to be fabricated as one solid, continuous, three-dimensional cam, but it developed that the state of technology presently available is not sufficient to fabricate such a cam. It was therefore decided to fabricate the cam with five separate profiles, each of which would accommodate a range of altitudes. The configuration of the cam is shown in Fig. 7-8. The first approach was to maintain the cam as a solid piece, and finish the profile contours by hand; this satisfied the requirements but left no margin for error. The second approach was to construct a segmental cam consisting of five profiles mounted on one body such that the profiles may be positioned relative to each other. This approach provided greater latitude in positioning of the cams but did not decrease the accuracy necessary to complete the cam contour. Figs. 7-9 and 7-10 illustrate the second cam arrangement.

The focus cam was calibrated at three separate conditions of altitude but at a fixed input tilt angle of 15 degrees. The altitudes chosen were the maximum and the minimum limits of the altitude range and an intermediate altitude which was near but not at the geometric mean. The data obtained at these positions determined the contour of three of the five profiles and the remaining profiles were obtained as the geometric mean between the calibrated profiles.

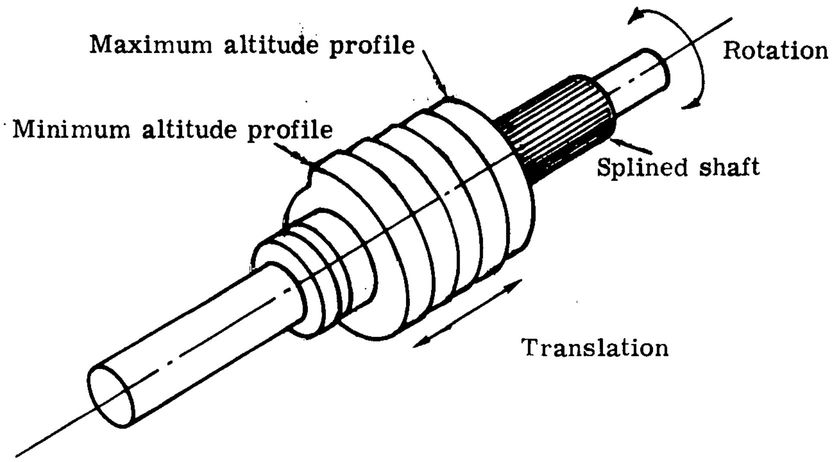


Fig. 7-8 — Solid focus cam

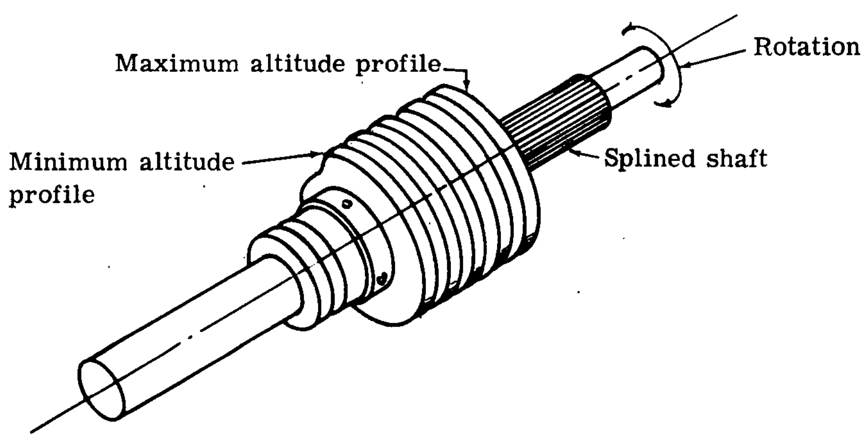
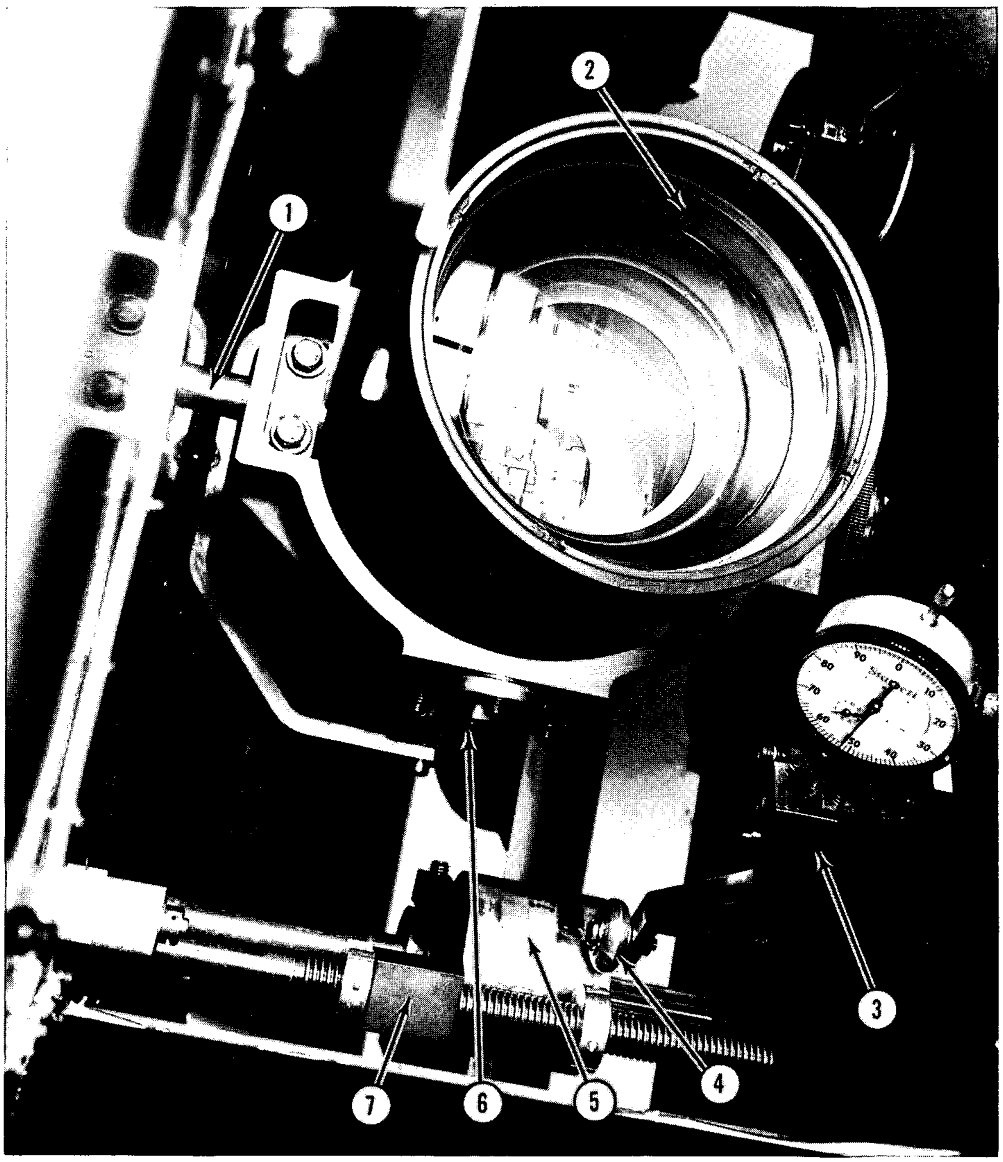


Fig. 7-9 — Segmented cam



9886

1 Focus control axis (γ axis)
2 Lens
3 Rack
4 Cam follower
5 Focus cam
6 Scheimpflug control axis
7 Cam translation control (shown disengaged)

Fig. 7-10 — Lens and focus cam

Method of Calibration

Fig. 7-11 illustrates the arrangement of the mechanism by which the lens was positioned relative to the scan arm by means of the focus cam. The focus cam is translated along the splined shaft such that the correct profile is positioned under the cam follower. The splined cam shaft is directly geared to the scan arm through a 3:1 gear train such that the active portion of the cam encompasses 240 degrees or ±120 degrees from nadir.

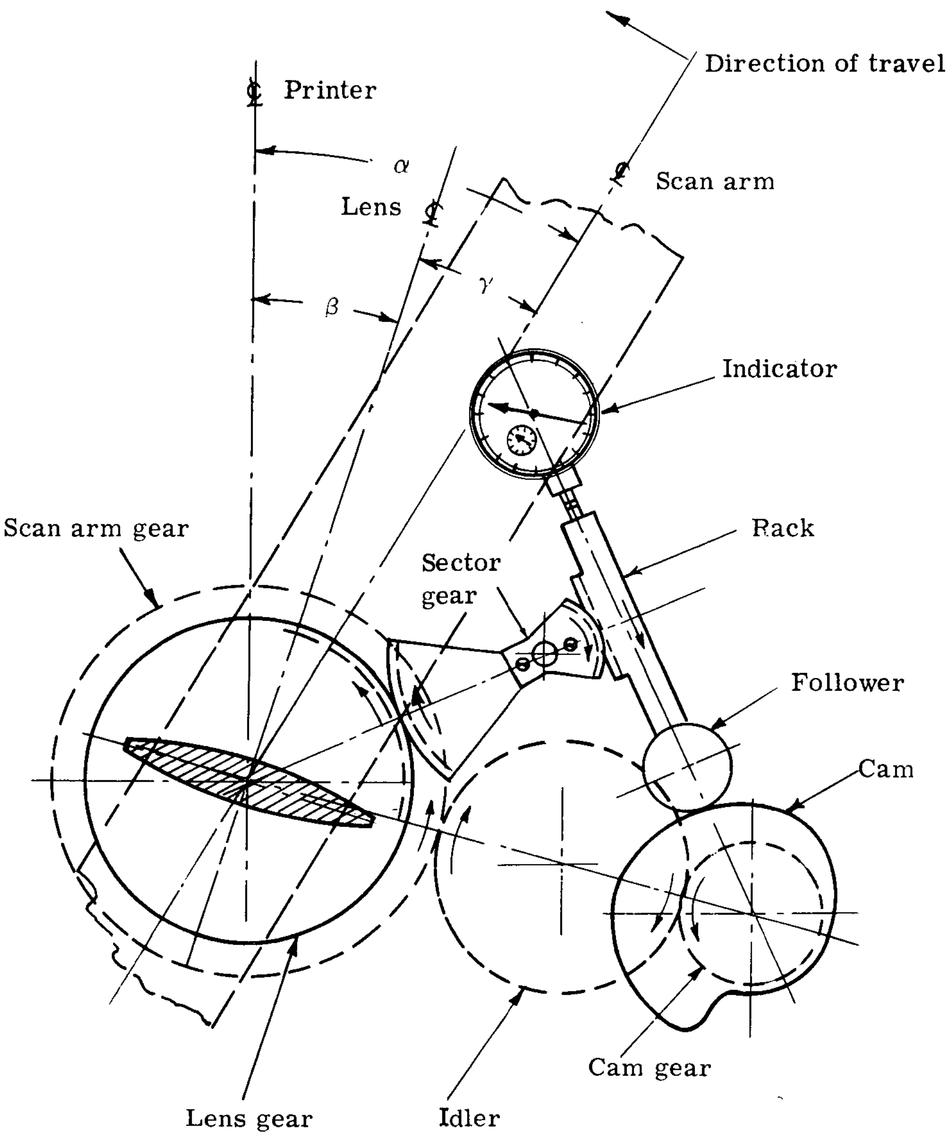


Fig. 7-11 — Lens drive mechanism

As the arm rotates about a common axis with the lens, its 6-inch-diameter gear drives a gear train that imparts rotation to the cam shaft in the same direction. The rack and follower arrangement follows the cam displacement directly. A sector gear mounted between the rack and the lens gear drives the lens assembly in the same direction as the arm but at a rate dictated by the cam profile. The complete assembly must be accurately positioned with no backlash in the gear trains. The ratio between the cam and the lens is such that 0.001-inch rack displacement equals 3 minutes angular movement of the lens. An indicator is fastened to the rack assembly so that actual rack displacements may be read directly.

The procedure for setting the indicator prior to actual calibration is as follows:

1. Locate the scan arm exactly at nadir and clamp it in place.
2. Set a gauge (similar to that illustrated in Fig. 7-12) on the cam shaft such that the distance between the axis of the cam shaft and the axis of the cam follower is 2.0167 inches.

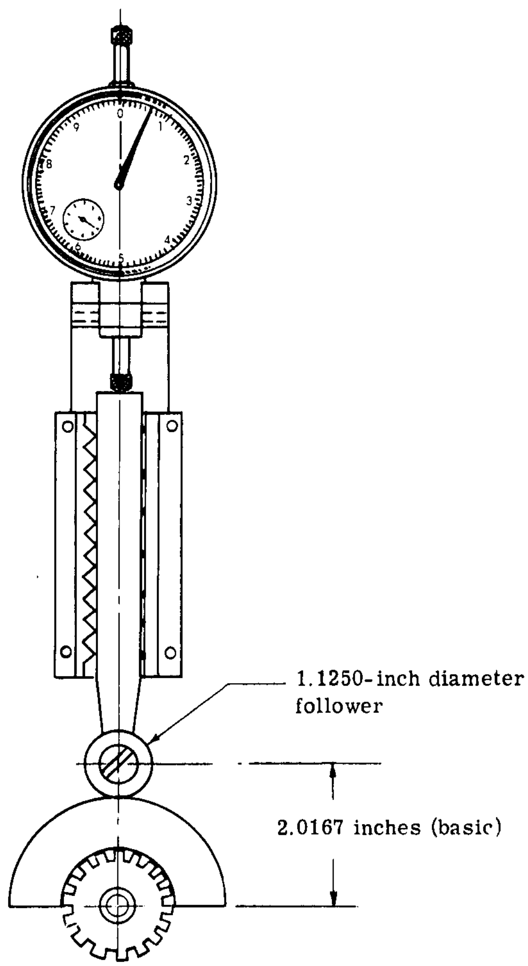


Fig. 7-12 — Indicator alignment

3. Set the indicator to read 0.350 inch. (The cam displacement is approximately ±0.250 inch.) Any other setting may be chosen but 0.350 inch suited our purposes.
4. Remove the gauge and replace it with a dummy cam whose slope is about 0.030 inch in 15 degrees.
5. Loosen the cam gear and set the cam such that the indicator reads 0.350 inch.
6. Check the optical axis alignment of the projection lens by the method explained in Section 7.2.3.

NOTE

If the optical axis is not aligned do not change the cam setting but make the proper alignment by loosening the two screws on the adjustable sector gear and adjusting it to the correct setting. Fasten the screws when alignment has been obtained and recheck to ensure that the gears did not slip during the securing operation.

7. Install the condenser system in place.
8. Place a neutral density filter between the slit and the film plane. (We used a neutral density value of 1.3.)
9. Connect an electronic timer similar to the Tektronix TM-8 to the projection lamp circuit.
10. Place a 70-millimeter film strip in the platen. The strip should have three targets in line across the width of the film. The targets should be high contrast USAF 1951 targets with clear lines on an opaque background.
11. Position a target series centrally under the slit.
12. Locate the plane of best focus at nadir for conditions of maximum, mean, and minimum altitudes at tilt angles of 0 and 15 degrees. This is accomplished by making a series of exposures at conjugate settings that approximate the theoretical data. Average the displacements with respect to peak resolution and establish a conjugate datum.
13. Position the scan arm accurately at a scan angle, x. Settings should be made at 5-degree increments for ±40 degrees of α. (The indicator should change by approximately 0.030 inch for every 5-degree change in α.)
14. Loosen the cam gear and move the cam so that exposures may be made in 0.001-inch increments for a range of ±0.010 inch from the ideal setting.
15. Analyze the resolution data and record the position of peak resolution.
16. Plot this data and join the points by straight lines. Do not smooth the curve.
17. Take additional exposures at any point that is doubtful.
18. Use the curve to determine the cam displacement schedule at 1-degree cam intervals.

7.6.2 Scheimpflug Mechanism

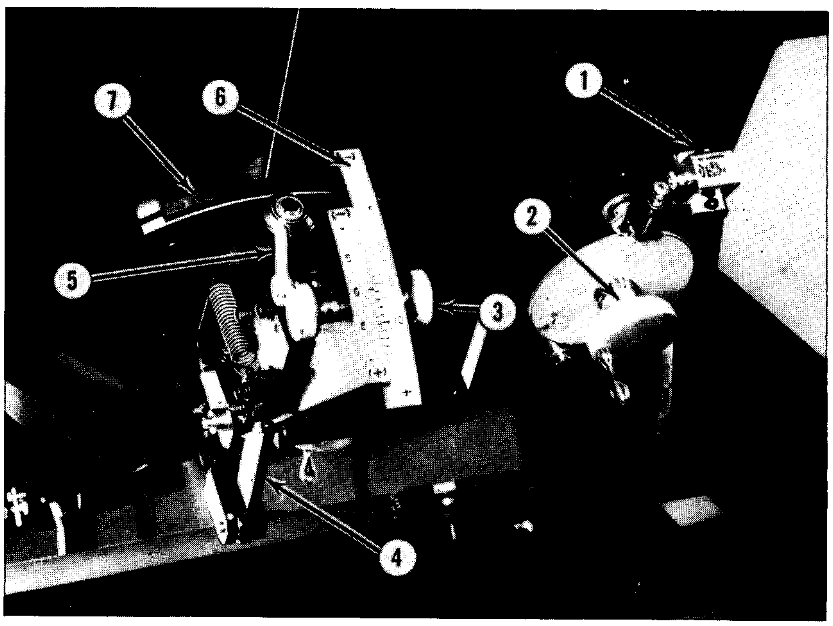
The setting of the Scheimpflug angle for optimum results is very sensitive. The relationship exists that

$$\cos \eta = \cos \phi \cos \gamma$$

where η = total focus angle
ϕ = Scheimpflug lens tilt angle
γ = angle between the centerlines of the scan arm and lens in the plane of scan

For any particular cam profile used for a range of altitudes, the contour was determined at the primary tilt angle of 15 degrees. As the primary tilt angle (or altitude) changes, there is a corresponding change in the focus angle, but the gamma angle is maintained constant for any scan angle position. It can be seen that the angle, ϕ, should then change to accommodate the change in η.

Normally this slight angular change is within the depth of focus of the lens, and the Scheimpflug angle, ϕ, may be set at the value for nadir position and maintained throughout the desired scan (see Fig. 7-13). This original assumption has been proven valid by actual tests; resolution values were equal to or above specifications. It was also proven that the resolution could be increased at the extreme limits of the input ranges by slightly changing the Scheimpflug angle.



9882

1 Focus indicator
2 Focus control
3 Scheimpflug control knob
4 Control linkage
5 Lock
6 Scheimpflug indicator
7 Scheimpflug cam

Fig. 7-13 — Scheimpflug control and indicator

These tests were conducted under static conditions and verified by dynamic tests. The method of test is as follows (refer to Fig. 7-14):

1. Set the printer for a combination of input altitude and tilt.
2. Set the scan arm at an angle α.
3. Determine the point of sharp focus by setting the cam to the optimum γ angle.
4. Make exposures in ± 0.05-degree increments either side of the setting of ϕ, determined at nadir, that corresponds with the input parameters.
5. Make dynamic exposure runs at the settings determined by the static tests and check the resolution at the points that correspond with the scan angle.

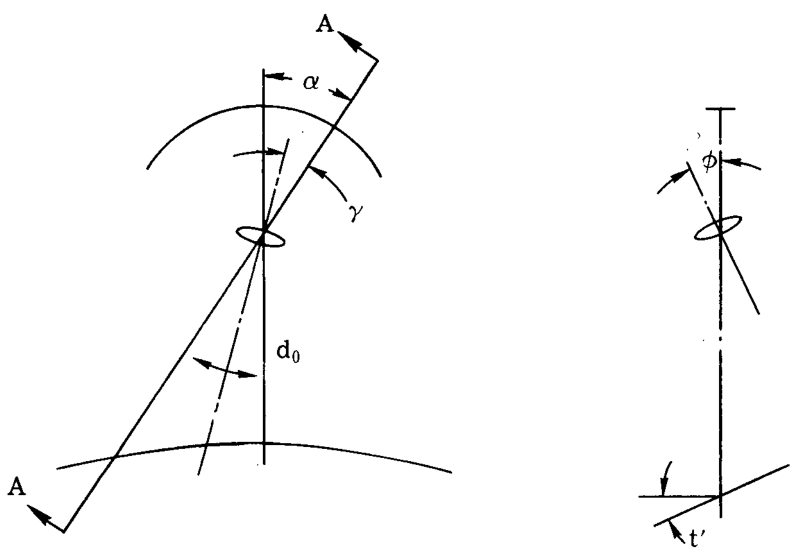


Fig. 7-14 — Scheimpflug test diagram

Tables 7-2, 7-3, and 7-4 present the results of some of the tests conducted.

An analysis of the data obtained indicated that the resolution could be maintained at a high level throughout the format by varying the Scheimpflug angle during the scan cycle. A modification was made to the Scheimpflug mechanism that allowed for interchangeability of different plate cams to accommodate different input parameters. The displacement schedule of these cams must be empirically determined in the following manner:

1. Set the arm at some scan angle.
2. Record the value shown on the rack indicator and determine the rack displacement from nadir.
3. Convert this displacement into angular lens displacement from nadir (0.001-inch rack displacement equals 3 minutes angular lens displacement).

4. Conduct a static Scheimpflug resolution test.
5. Determine the angular shift desired for peak resolution.
6. Convert the angular shift into cam displacement (the plate cam is positioned at a 5.000-inch radius from the main axis of lens rotation).

By following the steps outlined, a series of cams may be prepared that will provide optimum resolution over the complete range of input parameters.

Table 7-2 — Resolution in Lines Per Millimeter Obtained During Dynamic Exposure Tests—Maximum Altitude at Tilt of 10 Degrees, Computed Nadir Value of Scheimpflug 3.71 Degrees

	α, degrees						
ϕ, degrees	−35	−30	−20	0	+20	+30	+35
3.40	36-36-45	91-91-64	72-64-51	91-64-36	81-57-45	—	—
3.45	36-45-64	102-91-72	81-64-57	91-72-45	91-64-57	81-51-51	—
3.50	40-51-64	102-91-72	81-64-64	102-91-72	91-81-64	91-72-64	64-57-51
3.55	45-51-72	91-91-81	81-72-64	102-81-81	91-81-81	91-81-81	72-64-64
3.60	45-57-72	102-91-81	91-81-81	102-91-91	91-91-81	91-81-81	72-64-64
3.65	51-64-72	91-91-81	91-91-91	114-102-91	91-91-91	91-91-91	72-72-64
3.70	52-72-81	91-91-81	91-91-91	114-102-102	91-91-81	91-91-91	72-64-72
3.75	52-72-81	91-81-72	91-91-91	102-114-91	91-91-91	91-91-81	81-81-81
3.80	57-81-81	91-81-72	91-91-91	114-114-91	91-91-91	91-81-72	81-81-72
3.85	57-72-81	91-72-64	91-91-81	102-91-64	91-81-81	91-81-72	81-81-64
3.90	57-72-72	91-64-57	102-91-81	81-71-57	91-81-72	91-81-72	81-81-64

Table 7-3 — Resolution in Lines Per Millimeter Obtained During Dynamic Exposure Tests—Maximum Altitude at Tilt of 15 Degrees, Computed Nadir Value of Scheimpflug 5.62 Degrees

	α , degrees						
ϕ, degrees	−35	−30	−20	0	+20	+30	+35
5.30	57-64-81	57-72-81	40-40-64	—	—	—	—
5.35	64-72-72	81-91-102	40-57-72	—	—	—	—
5.40	72-81-91	91-91-102	51-57-81	—	91-64-57	—	—
5.45	72-81-81	91-91-102	57-57-81	—	91-72-72	57-51-57	64-57-57
5.50	72-91-81	91-91-91	72-72-81	—	91-91-91	72-64-64	72-64-57
5.55	81-81-91	81-91-91	91-81-81	81-91-91	91-91-91	72-72-72	72-72-64
5.60	81-81-81	81-91-91	102-91-91	91-91-91	91-91-91	91-81-81	72-81-64
5.65	72-81-91	72-72-81	102-91-102	91-114-102	91-91-91	102-102-91	81-81-64
5.70	57-72-81	64-72-81	91-91-102	81-91-102	91-81-81	102-91-81	81-81-64
5.75	57-81-81	51-72-81	91-91-102	81-91-102	81-81-72	102-81-81	81-81-64
5.80	45-81-81	40-64-81	81-91-91	—	81-72-64	91-81-72	81-81-64

Table 7-4 — Resolution in Lines Per Millimeter Obtained During Dynamic Exposure Tests—Maximum Altitude at Tilt of 20 Degrees, Computed Nadir Value of Scheimpflug 7.59 Degrees

	α, degrees						
ϕ, degrees	−35	−30	−20	0	+20	+30	+35
7.25	64-64-57	91-72-57	—	—	—	—	—
7.30	64-72-64	102-91-64	—	—	—	—	—
7.35	81-72-64	102-81-64	—	—	—	64-57-51	64-57-51
7.40	81-81-72	102-91-72	64-57-57	—	72-57-57	91-72-57	72-64-57
7.45	81-81-72	91-91-72	81-72-72	—	81-64-64	91-91-81	72-64-57
7.50	81-81-64	91-91-72	81-72-81	72-57-51	81-81-81	91-91-81	81-72-64
7.55	72-72-57	81-81-64	91-91-91	81-72-72	91-81-81	91-91-81	81-81-64
7.60	72-64-51	72-72-64	91-91-91	91-81-72	91-81-81	91-81-72	81-81-64
7.65	64-57-45	—	91-81-81	91-81-91	81-81-81	81-81-64	81-72-64
7.70	—	—	91-72-72	91-91-91	81-81-64	81-81-64	81-72-64
7.75	—	—	81-72-64	91-91-81	72-72-57	72-72-57	72-64-57
7.80	—	—	—	81-72-72	72-72-57	72-64-51	72-64-51

7.7 SLIDE RULE

It was assumed at the start of this contract that a simple calculator could be fabricated to give the settings for the equipment. As time progressed it became evident that the calculator must be sophisticated and that it must be engraved individually for each piece of equipment, since all settings are dependent on the focal length of the particular lens. The input parameters given to an operator for any particular frame of panoramic photography are:

1. Flying height of the taking system, H
2. Pitch angle of the taking system, t
3. Roll angle of the taking system, roll
4. Density of the input photography, exposure.

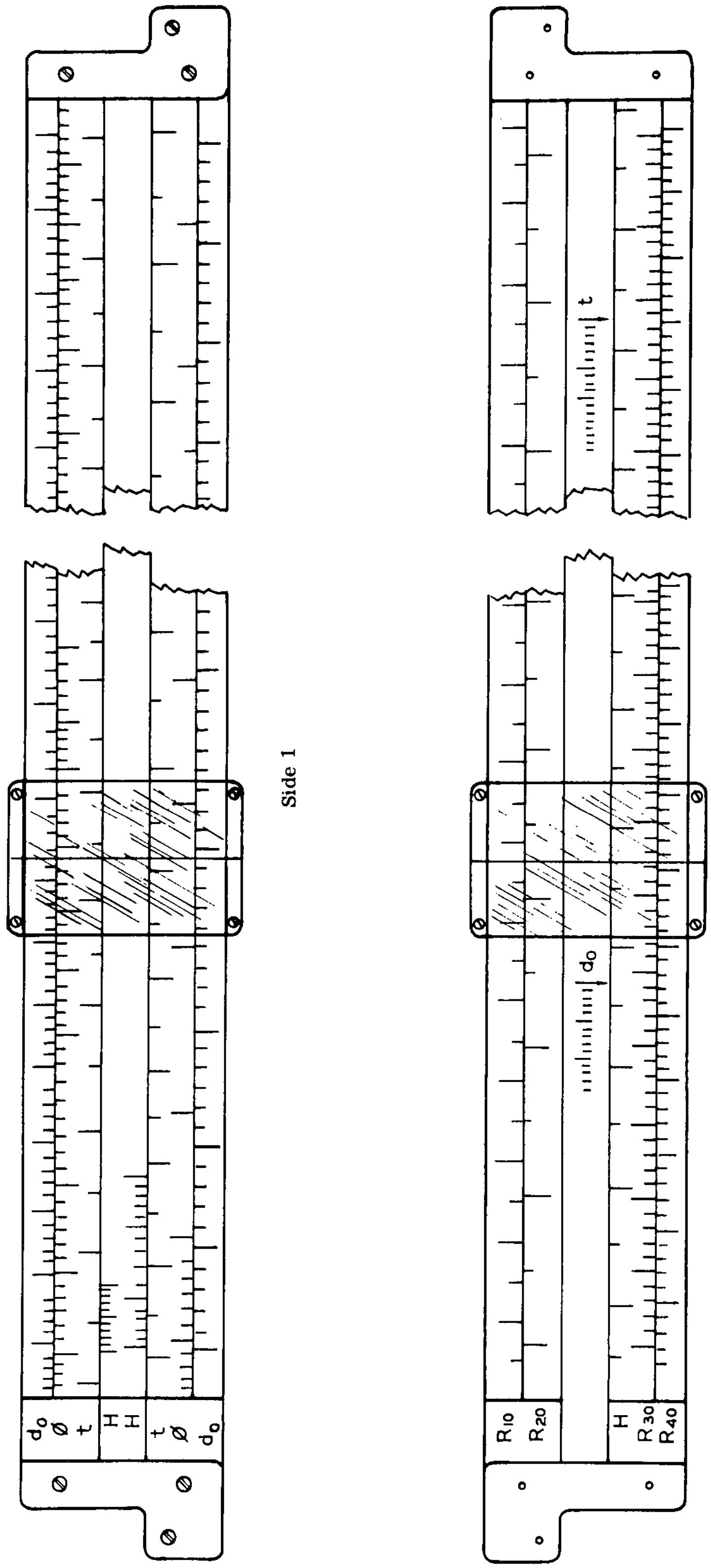
The exposure setting is set directly on the printer by the operator as a function of total scan time, and the roll is set directly by means of the roll indicator. The proper focus cam profile is chosen as a direct function of flying height, H.

The combination of flying height, H, and pitch angle, t, are used in conjuction with the slide rule to obtain the corresponding values of

1. Easel tilt, t'
2. Lens tilt, ϕ
3. Change in conjugate, d_0
4. Easel radius of curvature, R

The value for R is not given directly, but the displacement values of the indicators at the respective chordal distances are obtained directly as values for R_{10}, R_{20}, R_{30}, and R_{40}.

Fig. 7-15 illustrates the slide rule arrangement and the scales found on both sides. The slide rule consists of two fixed members, an index slide, and a movable indicator. Side 1 of the rule has three scales on each of the fixed members and two scales on the index slide. The upper fixed member is used to obtain values for tilt angles between 0 and 6 degrees. The lower fixed member is



Side 1

Side 2

Fig. 7-15 — Slide rule

used for values between 10 and 20 degrees. Values between 6 and 10 degrees are not included so as to keep the slide rule within workable proportions. However, these values may be obtained by interpolating the values obtained between 5 and 10 degrees.

The scales on the upper and lower sections are marked to correspond with easel conjugate setting, d_0, lens Scheimpflug setting, ϕ, and tilt angle, t. The index slide has two scales to correspond with the flight altitude, H.

The reverse side (side 2) of the rule has two scales on the upper fixed member, three scales on the lower fixed member, and two scales on the index slide. The upper scales are used to obtain values for setting easel curvature at locations R_{10} and R_{20}. The lower scales are used for values of R_{30} and R_{40}, as well as flight altitude, H. The index is used for values of easel conjugate, d_0, and tilt angle, t.

7.7.1 Slide Rule Settings

Slide rule settings to be used by the operator in adjusting the printer for each frame are determined by the following procedures.

To determine the easel tilt angle, t′, the lens Scheimpflug angle, ϕ, and the easel conjugate setting, d_0, from the input parameters of primary tilt angle, t, and flight altitude, H, use the following procedure:

1. Position the index of the appropriate H scale opposite the given tilt angle on the corresponding t scale.
2. Move the indicator and position the witness mark at the given flight altitude on the appropriate H scale.
3. Read the easel tilt angle from the corresponding t scale.
4. Read the lens Scheimpflug angle from the corresponding ϕ scale.
5. Read the easel conjugate setting from the corresponding d_0 scale.

To determine the indicator settings for controlling the easel curvature, use side 2 of the slide rule and apply the following procedure:

1. Position the index of the easel conjugate setting, d_0, at the given value on the H scale.
2. Position the indicator at the previously determined value of easel conjugate setting on the d_0 scale.
3. Position the index of the t scale at the indicator witness mark.
4. Position the indicator at the given value of tilt angle, t.
5. Read the values of R_{10}, R_{20}, R_{30}, and R_{40} from the appropriate scales as shown by the indicator witness mark.

7.7.2 Scale Calculations

To have the slide rule engraved, the following expressions were derived to obtain scale values in millimeters.

Side 1

For tilts varying from near 0 to 5 degrees:

$$t \text{ scale in millimeters} = 564.444444\,(\log \sin t + 2.060)$$

and

$$\phi \text{ scale in millimeters} = 564.444444\,(\log \sin t + 2.060)$$

where $\tan t = \sin \phi/(\cos \phi - f/F)$

f = focal length of the lens

F = focal length of the taking system (24.000 inches)

$$H \text{ scale in millimeters} = 564.444444\,[\log(1 + H/R)]$$

where H = altitude

R = means radius of earth curvature

$$d_0 \text{ scale in millimeters} = 564.444444\,(\log \sin t + 2.060)$$

where $\cos \phi = f/F + (f/d_0)\ \sin \phi = +\ (1 - \cos^2 \phi)^{1/2}$

$\tan t \quad \sin \phi/(\cos \phi - f/F)$

For tilts varying from 10 to 20 degrees:

$$t \text{ scale in millimeters} = 1852.887538\,(\log \sin t + 0.761)$$

$$H \text{ scale in millimeters} = 1852.887538 \left[\log\left(1 + \frac{H}{R}\right)\right]$$

$$\phi \text{ scale in millimeters} = 1852.887538\,(\log \sin t + 0.761)$$

where $\tan t = \sin \phi/(\cos \phi - f/F)$

$$d_0 \text{ scale in millimeters} = 1852.887538\,(\log \sin t + 0.761)$$

where $\cos \phi = f/F + f/d_0$

$\tan t = \sin \phi/(\cos \phi - f/F)$

Side 2

$$H \text{ scale in millimeters} = 1321.665272 \left(\log \frac{48R}{H} - 2.762\right)$$

$$d_0 \text{ scale in millimeters} = 1321.665272 \left(\log \frac{d_0}{48}\right)$$

$$t \text{ scale in millimeters} = 1321.665272 \left[\log \frac{\cos(t + 0.4°)}{\cos 0.40°}\right]$$

$$R_{10} \text{ scale in millimeters} = 1321.665272 \left(\log \frac{R}{2 \sin^2 \theta} - 2.762\right)$$

where $\tan \theta = R/10$

$$R_{20} \text{ scale in millimeters} = 1321.665272 \left(\log \frac{R}{2 \sin^2 \theta} - 2.762\right)$$

where $\tan \theta = R/20$

$$R_{30} \text{ scale in millimeters} = 1321.665272 \left(\log \frac{R}{2 \sin^2 \theta} - 2.762\right)$$

where $\tan \theta = R/30$

$$R_{40} \text{ scale in millimeters} = 1321.665272 \left(\log \frac{R}{2 \sin^2 \theta} - 2.762\right)$$

where $\tan \theta = R/40$

8. DIAGNOSTIC CONSIDERATIONS

25X1 [redacted] does not anticipate the loss of calibration or alignment of the Gamma I Rectifying Printer if it is operated and maintained in a conscientious manner. There are, however, certain indications of misalignment or loss of calibration that can be readily detected should an accident occur. We recommend that periodic tests be made for resolution and accuracy to ensure that the instrument is performing at optimum conditions.

8.1 SCHEIMPFLUG CONDITION

The Scheimpflug condition (see Fig. 8-1) states that if the entire plane, L, is to be sharply imaged in plane, E′, through the lens, O, two optical conditions must be fulfilled:

1. The distances, a and a′, of a point, P, in the plane, L, and its image point, P′, in the plane, E′, measured along the optical axis, must satisfy the lens equation

$$\frac{1}{a} + \frac{1}{a'} = \frac{1}{f}$$

where f = focal length of lens

2. The planes L and E′ and the mean plane, M, of the lens must intersect in a straight line through V.

It should be readily seen that if either the lens or the easel is set at an improper angle, the plane of sharp focus will not fall properly on the easel (see Fig. 8-2).

Although a slight angular mismatch can be tolerated at nadir because of the lens depth of focus, this condition would cause degradation at the extremes of scan.

8.2 EASEL TILT

The indications that the lens or easel is improperly set but at the proper conjugate distance are that the resolution is high on the central axis and low on either side. This is illustrated in Fig. 8-3.

Assume that three targets in line are situated at the input film plane. The targets are positioned perpendicular to the scan direction and are designated A, B, C, with target A located at the front of the input plane, target B at the rear of the input plane, and target C at the center of projection of the input plane. The images of these targets on film at the easel are designated as A′, B′, and C′. It can be seen that images A′ and B′ lie outside the depth of focus and therefore the resolution must, of necessity, be lower than the resolution at image C′, which is at the correct plane of focus.

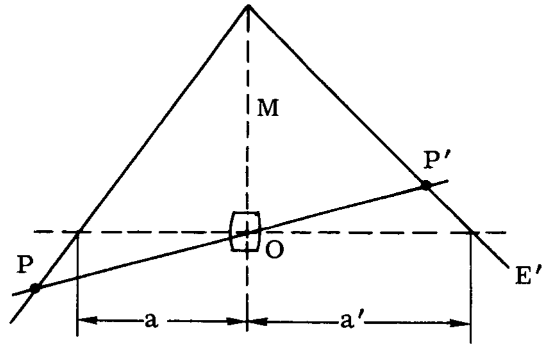


Fig. 8-1 — Scheimpflug condition

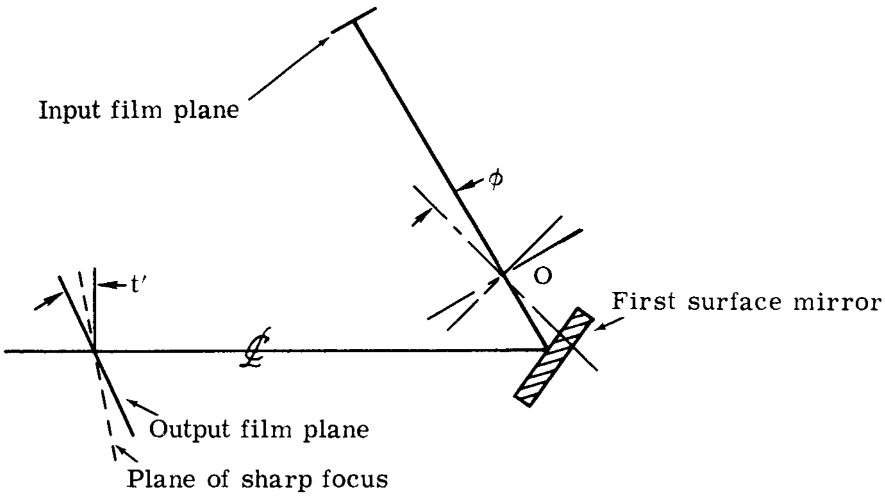


Fig. 8-2 — Effect of an improper lens or easel angle on the plane of sharp focus

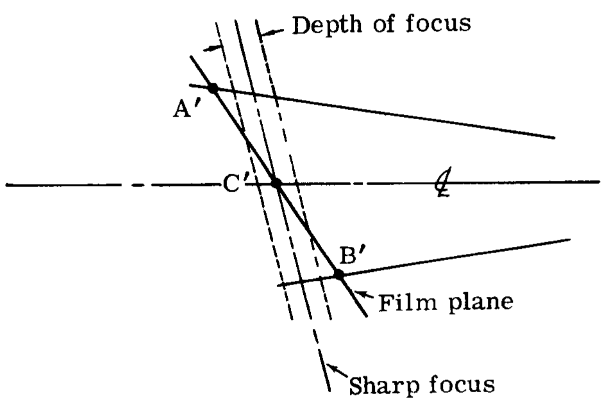


Fig. 8-3 — Effect on sharp focus of an improperly set lens or easel angle at the proper conjugate distance

If this situation is found to exist, the vernier settings of lens tilt, ϕ, and easel tilt, t', should be checked with the slide rule. The error should be uncovered by these checks, but if not, check the input film to ascertain that it is properly positioned on the guide rails and lift rollers, then check the optical alignment of the lens and the easel against the zero settings of the verniers by the following steps:

1. Position and lock the scan arm at nadir.
2. Remove the condenser system and projection lamp from the lamp housing.
3. Position a beam splitter on the film lift rollers.
4. Position a first surface mirror on the top surface of the lens cell.
5. Position the lens tilt vernier at zero and lock it in position.
6. Use the squaring-on eyepiece and flashlight to check the reflections from the beam splitter and the first mirror.
7. If the images are not coincident, adjust the turnbuckle between the vernier arm and the lens until the images are coincident. (This is a two-man operation.) Lock the turnbuckle when alignment is achieved.
8. Remove the first surface mirror from the lens.
9. Set the easel to read zero on its vernier.
10. Place a first surface mirror in position on the easel at nadir.
11. Using the squaring-on eyepiece and flashlight, observe the reflection of the light transmitted through the lens to the easel and back to the beam splitter at the film lift roller. The images should be coincident.
12. If coincidence is not achieved, position the easel until alignment is achieved, and correct the zero setting of the vernier.
13. Restore the rectifier to operational condition.

8.3 OUTPUT CONJUGATE

To maintain sharp focus across the width of the film, the long conjugate of the projection system must be at the proper distance to satisfy the lens equation. The effects of an improper conjugate setting are illustrated in Fig. 8-4.

It can be seen that all three film images, A′, B′, and C′, lie outside the depth of focus at the image plane. This condition can be easily corrected by taking photographic static tests at nadir for extremes of altitude and tilt settings and adjusting the conjugate datum to a value determined from the data obtained. The datum should be set such that the relative displacements from the datum for particular settings of altitude and tilt will allow the highest resolution values to be obtained.

A combination of improper settings of tilt angles and conjugates will give results as illustrated by Fig. 8-5. It can be seen that the image at A′ would be in sharp focus, the image at B′ would be out of focus, and the image at C′ would be a value between that at A′ and B′. If this condition exists, it will be necessary to correct the tilt angles and the conjugate to obtain the optimum values.

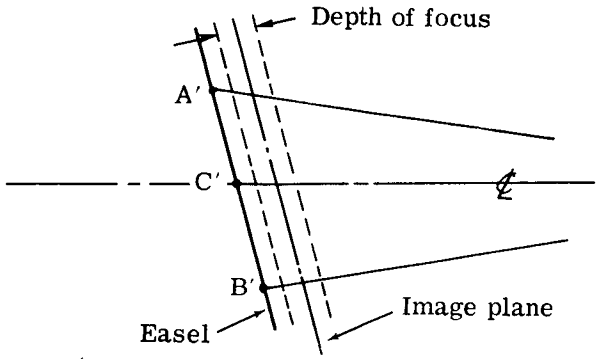


Fig. 8-4 — Effect of an improper conjugate distance setting

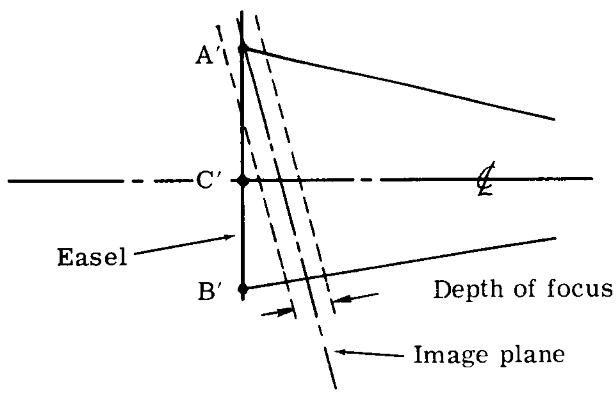


Fig. 8-5 — Effect of improper tilt angle and conjugate distance settings

8.4 FOCUS CAM

If an operator should inadvertently strike the Scheimpflug vernier mechanism and change the angular relationship between the lens and the focus cam, the resolution degradation at the extremes of scan will be great. The Scheimpflug vernier mechanism may be manually rotated clockwise in the scan direction to raise the cam follower from the cam (through the gear train) so that the cam may be positioned to a different profile. If the vernier mechanism is released suddenly, or if the mechanism is jolted in a counterclockwise direction, the gear train would tend to force the follower into the cam, and since both pieces are solid, the strain would have to be taken elsewhere. The gear ratio is such that the force applied is magnified.

The only place that the excess strain can be accommodated is at the sector gear between the lens gear and the cam follower rack. This sector gear is fabricated in two sections held together by two screws, and the relative angular position of these two sections can be shifted by excessive force.

If severe loss of resolution at the ends of scan is noticed at various instrument settings, this condition should be immediately suspected and the following steps should be followed:

1. Position and lock the scan arm at nadir.
2. Remove the condenser system and projection lamp from the lamp housing.
3. Position a beam splitter on the film lift rollers.
4. Position a first surface mirror on the top surface of the lens cell.
5. Position the lens tilt vernier at zero and lock it in place.
6. Select a cam profile and set the cam follower on that profile.
7. Loosen the cam gear, if necessary, and set the cam such that the indicator shows the correct setting for the nadir position of the cam at the desired profile.
8. Use the squaring-on eyepiece and flashlight to check the reflections from the beam splitter and the first surface mirror.
9. If the images are not coincident, loosen the two socket head screws holding the sector gears together and adjust the angular position of the sectors until the images are aligned. (This is a two-man operation.)
10. Secure the sector gears and check that the alignment does not shift.
11. Restore the rectifier to its operational condition.

8.5 INPUT FILM

Improper geometry and poor resolution can be obtained if the input film is not positioned properly on the platen. The causes of this improper positioning are as follows:

1. The film is on top of the sliding nadir indicator rather than under it as a result of the nadir indicator being in the forward position during film loading.
2. A heat splice or a poor butt splice near the platen causes film buckling which will cause the film to shift during scan.
3. Improper alignment of leader and film strip during the splicing operation causes the film to skew over the platen rather than to lie in a cylindrical form.

4. Wide film or a wide splice joint will cause the film to buckle between the rails and not lie in a cylindrical form.

5. Misalignment of the film transport system can cause the film to skew over the platen.

The correction of these faults is straightforward and the proper steps can be taken when the condition is ascertained.

8.6 OUTPUT FILM

The output film alignment, length of transport, and inoperation of the film transport are discussed in the following paragraphs.

8.6.1 Alignment

The output film could, on occasion, have a slight buckle that would prevent it from being pulled flat against the easel by the vacuum system. The usual cause of this condition is nonalignment of the supply or takeup assemblies. This condition can be corrected as follows:

1. Load the supply side with a full spool of film.
2. Thread the film through the easel and onto the takeup spool.
3. Raise the scan arm drive roller from the track and position the scan arm away from the limit switches.
4. Activate the RESET button on the control chassis. This will institute a transport cycle.
5. Note how the film is being transported, and if it buckles, note where the buckle occurs.
6. Loosen the four screws holding either the supply or takeup assemblies to the main support.
7. Adjust the appropriate assembly to provide smooth tracking of the film across the easel.
8. Lock the assemblies in position, and transport sufficient cycles of film to ensure that the tracking is correct.

8.6.2 Length of Transport

The amount of film transported at the completion of each exposure cycle is governed by the timing cams and switches. The ratio between the number of revolutions of the drive roller and the single revolution of the cam shaft is governed by a variable ratio gear reducer located on the lower section of the takeup assembly. The reducer unit has a lever whose position determines the desired ratio. A clockwise movement increases the reduction ratio and permits a greater amount of film to be transported; conversely, a counterclockwise movement of the lever decreases the ratio and reduces the amount of film transported.

8.6.3 Transport Inoperative

Occasionally, the film transport system will not operate at the end of an exposure cycle. The reason for this is that the timing cams are not in their proper position. This may be caused by two conditions:

1. The cams were not set when the 9 ½-inch film was loaded.
2. The equipment was shut down before the transport cycle was complete and the cams were not reset when power was restored.

25X1

These conditions may be corrected by removing power from the equipment, setting the cams through manual rotation of the drive roller until the switch actuators are just in the dwell on the cams, and restoring power to the equipment. Operate in a normal fashion after this is accomplished.

8.7 SCAN SPEED

The speed at which the scan arm is driven is a function of the angular position of the arm, and the variable velocity slope must be symmetrical about nadir. Should this arrangement be changed, it can be reset as follows by two men:

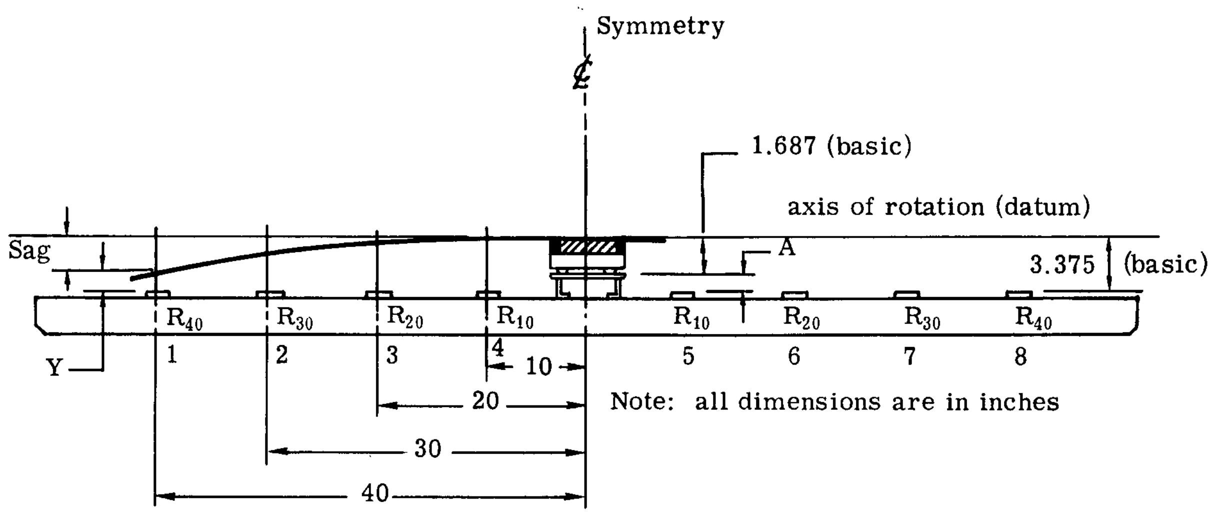
1. Raise the scan arm drive roller from the track.
2. Position the arm at nadir.
3. Connect a dc voltmeter across TB109-3 and -4. Use a scale in excess of 100 volts and check polarity when power is applied.
4. Set the SCAN TIME selector on the control panel to zero.
5. Activate the PRINT button and observe the voltage reading.
6. The arm of the variable transformer, T102, should be set in a roughly vertical attitude midway in its total travel.
7. The voltage reading at this time should be about 98 vdc.
8. Adjust the cam to activate switch S108 just prior to the arm being positioned at nadir.
9. Position the arm at +40 degrees and record the voltage reading.
10. Position the arm at −40 degrees and observe the voltage reading. It should agree with that obtained at +40 degrees.
11. If the voltages do not agree, loosen the gear on the variable transformer shaft and rotate the shaft until the voltage reads about midway between the readings previously obtained.
12. Return the arm to nadir and readjust the cam.
13. Position the arm at +40 degrees and −40 degrees and compare the readings.
14. Continue the previous steps until a balanced condition exists.
15. Tighten the gear and the cam at the completion of each check.

8.8 EASEL CURVATURE

The easel plate has been calibrated and aligned at the place of manufacture; all indicators were set to zero at the radius of curvature that corresponds to the value obtained for input parameters of maximum altitude and 20 degrees primary tilt. The method used to establish this radius was as follows (refer to Fig. 8-6):

1. Measure the actual dimension, A, of each of the machined pads from numbers 1 through 8 and record the dimensions.
2. Add the dimensions obtained to a basic figure of 1.687 and record the sum.
3. Subtract the value of the sag for the particular station and obtain a value, Y, for the setting of the easel.

These values obtained are set into the easel and each time that a station is set, all the previous settings are rechecked to ensure that a shift did not occur. When all settings have been checked, the indicators are set in place and the dial is positioned to read zero. Particular care must be exercised during this alignment to ensure the final accuracy of the output.



Dimension A (actual), inches

Station	1	2	3	4	5	6	7	8
Serial number 1	1.655	1.677	1.684	1.690	1.689	1.693	1.697	1.689
Serial number 2	1.699	1.680	1.688	1.687	1.682	1.680	1.685	1.689

Dimension Y, inches

Station	1	2	3	4	5	6	7	8
Serial number 1	1.961	2.588	3.026	3.291	3.290	3.035	2.608	1.995
Serial number 2	2.005	2.591	3.030	3.288	3.283	3.024	2.596	1.995

	R_{10}	R_{20}	R_{30}	R_{40}
Maximum sag, inches	0.086	0.345	0.776	1.381

Fig. 8-6 — Method used to establish easel radius of curvature

9. RECOMMENDED TEST AND ACCEPTANCE PROCEDURE

It is recommended that a test and acceptance procedure of the type and format described in this section be included as part of the equipment contract.

9.1 SCOPE

This section covers the tests and procedures necessary to prepare acceptance of the Gamma I Rectifying Printer. Completion of these tests will signify that the equipment has been satisfactorily assembled and that it will meet customer acceptance.

The following specifications (of the issue in effect on date of invitation for bids), documents, and drawings form a part of this specification to the extent indicated below:

- Design Specification, Gamma I Printer, 10 April 1963
- Drawing J59100 Assembly, Gamma I Printer
- Drawing J59109 Schematic, Gamma I Rectifier.

9.2 REQUIREMENTS

This section discusses test and procedure requirements for the Gamma I Rectifying Printer.

9.2.1 Inspection

Inspection shall be performed as described in Section 9.4 and in accordance with the procedures described in Section 9.3.

9.2.2 Functional Test

The printer shall be tested as described in Section 9.5 and in accordance with the procedures described in Section 9.3.

9.2.3 Photographic Test

Photographic tests shall be performed as described in Section 9.6 and in accordance with the procedures described in Section 9.3.

9.3 PROCEDURES

Procedures for inspections, functional tests, and photographic tests for the Gamma I Rectifying Printer are discussed in this section.

9.3.1 Inspection

Inspections shall be performed by project personnel and/or contracting agency representatives in the presence of [redacted] quality assurance personnel. Data sheets, see Appendix B, shall be used to

25X1

record all information obtained. Unsatisfactory conditions shall be expanded in the "Remarks" section of the data sheet, and action to remedy the condition shall be initiated. The cognizant test personnel shall sign the data sheet and indicate the date of test. The unsatisfactory conditions shall be reinspected upon completion of the remedial action, and the results noted on the data sheet.

When all areas are satisfactory, the data sheet shall be certified acceptable by signatures in the appropriate locations on the data sheets. In addition to the required signatures, the signers first initial and last name shall be legibly printed adjacent to the signature. The date of all signatures shall be indicated.

The completed data sheets shall become part of the project records and copies of the sheets shall be distributed to the contracting agency, if so desired by said agency. These sheets do not indicate final acceptance by the contracting agency.

9.3.2 Functional Tests

Functional tests shall be performed by project personnel in the presence of [redacted] quality 25X1
assurance personnel and contracting agency representatives cognizant of the operational capabilities of the printer. Data sheets (see Appendix B) shall be used in accordance with the procedure outlined in Section 9.3.1

9.3.3 Photographic Tests

Photographic tests shall be performed by project personnel in the presence of contracting
25X1 agency representatives and [redacted] quality assurance personnel cognizant of the printer capabilities. Data sheets (see Appendix B) shall be used in accordance with the procedure outlined in Section 9.3.1.

9.4 INSPECTIONS

9.4.1 Mechanical Inspection

The following inspections shall be made to ensure that the instrument is fabricated and
25X1 assembled in accordance with [redacted] standard practices. The drawings referenced in this specification shall supply the information necessary for inspection purposes. The test results shall be recorded as "Acceptable" or "Not Acceptable" on data sheet number 1 (see Appendix B).

Workmanship

Inspect the instrument for quality of workmanship in fabrication, assembly, and general appearance. This test shall be performed by quality assurance personnel.

Fasteners

Inspect all screws and securing devices for tightness. Ascertain that all components are firmly doweled or pinned as required by the referenced drawings. Any part secured by setscrews shall have the setscrew threads coated with Loc-Tite, or the part shall be modified to accept three setscrews. All screws that are Loc-Tited shall have a red indicating mark located at or near the pertinent screw. This test shall be performed by quality assurance personnel.

25X1

Gear Trains

Inspect all gears for binding, excessive backlash, burrs, metal chips, or dirt. Ascertain that all gears are lubricated with a light film of grease. This test shall be performed by quality assurance personnel.

Film Rollers

Inspect all rollers for freedom of rotation and/or swing. All rollers shall be clean and free of scratches and nicks. This test shall be performed by quality assurance personnel.

Lamp Housing

Inspect the projection lamp housing to ascertain that it is secured in position on the scan arm, and that the condenser housing and slit mechanism are fastened to the lamp housing. The assembly must be located such that the slit is approximately 1/4 inch above the 70-millimeter film plane.

Check that the flexible boot is in position between the housing and the fan assembly. Check that the light tight louver is in place at the rear of the fan support. This test shall be performed by quality assurance personnel.

Slit Mechanism

Manually adjust the slit control level and ascertain that the mechanism is capable of motion between the fully closed position and the fully open position (0 to 5 millimeters). Ascertain that the slit opening remains at whatever setting is desired until an exterior adjustment to another setting is made. This test shall be performed by quality assurance personnel.

V-Ways

Inspect all V ways for looseness or play. Check that there is no dirt or metal chips on the ways and that the ball retainers have the proper freedom of travel. Ascertain that there is no binding or chatter during travel and that the ways have been lubricated with a light film of grease. This test shall be performed by quality assurance personnel.

Easel Displacement Mechanism

Manually rotate the handle of the slide assembly and ascertain that the easel assembly moves moves fore and aft for a distance of 1.220 inches, with slight overtravel at each end of the travel range. Check that the motion is free of chatter. This test shall be performed by project personnel and be witnessed by quality assurance personnel.

Easel Tilt Mechanism

Manually rotate the easel tilt handwheel and ascertain that the easel assembly rotates over a range of −6 to +22 degrees. Check that the motion is free of chatter. This test shall be performed by project personnel and be witnessed by quality assurance personnel.

Lens Tilt Mechanism

Manually release the locking mechanism by rotating the locking handle toward the operator. Manually rotate the lens tilt knob and ascertain that the lens assembly moves from −2 to +8 degrees. Check that the motion is free and without chatter.

Lock the tilt mechanism in place and check that the assembly is locked in position.

This test shall be performed by project personnel and be witnessed by quality assurance personnel.

Focus Cam Position Mechanism

Manually move the lens tilt mechanism in a clockwise direction (facing the printer) to lift the cam follower from the cam surface. Rotate the cam positioning knob and note that the cam travels through its full displacement range. Gently release the lens tilt mechanism until the cam follower is in position on the cam surface. This test shall be performed by project personnel and be witnessed by quality assurance personnel.

Easel Curvature

Manually rotate the easel curvature knobs and ascertain that the indicators follow the motion in a smooth manner. Check that there is no binding or chatter. This test shall be performed by project personnel and be witnessed by quality assurance personnel.

Component Identification

Ascertain that every electrical and electronic component is clearly and legibly identified with its proper circuit designation as indicated on the referenced drawings. This test shall be performed by quality assurance personnel.

9.4.2 Optical Inspection

The following tests shall be performed by quality assurance personnel, and the results recorded on data sheet number 2 (Appendix B).

Projection Lamp

Inspect the projection lamp and ascertain that it is a type DFR lamp, rated at 500 watts when operated on a 115-volt, 60-cps power source. Check that the lamp is clean, properly located, and secured in its receptacle.

Projection Lens

Visually inspect the projection lens for cracks and/or chips. Check that the lens is clean and free of fingerprints or smudges, and that it is securely fastened in its gimbal. Ascertain that the lens stop is set at the central position (f/12).

Folding Mirror

Visually inspect the first surface of the folding mirror for cracks and/or chips within the active area of the surface. Check that the coated surface is free of scratches, fingerprints, smudges, and dust. Check that the mirror is in position on its support frame.

9.4.3 Electrical Inspection

The following tests shall be performed by quality assurance personnel, and the results recorded on data sheet number 3 (Appendix B).

Physical Inspection

Inspect all cables to ascertain that they are properly laced and clamped, and that all connections are firmly made. Check that all solder joints are firm and clean, all screw terminals are secure, and all crimped connectors are properly crimped.

Check all switches to ascertain that they operate freely and have sufficient overtravel.

Fuses

Inspect all fuses in the instrument for continuity, proper rating, and type, as specified on the schematic.

Lamps

Inspect all lamps for continuity and proper rating. Ascertain that they are securely mounted in their receptacles.

9.5 FUNCTIONAL POWER TESTS

Load the printer with 70-millimeter and 9 ½-inch film. The capacity of each film transport system is 500 feet. When the instrument is properly loaded, the following tests shall be performed by project personnel and be witnessed by quality assurance personnel. The test results shall be recorded on data sheet number 4 (Appendix B).

Ascertain that the scan arm is positioned at the stored position such that switch S105 or S106 is activated and that the scan arm drive wheel is in position on the track. Check that the VACUUM switch located on the chassis panel is in the ON position.

9.5.1 Main Power

Connect the printer to a 115-volt, 60-cps, single phase, 20-ampere, alternating current power source by means of the power cord provided. The receptacle that receives the connecting cable shall be of the "Twist-Lok" type with ground wire.

This connection will provide power to the printer but none of the components shall be activated.

9.5.2 Power On

Operate the POWER switch. This will cause power to be applied to the following components:

1. Vacuum turbine
2. Projection lamp fan
3. 70-millimeter film transport torque motor
4. 9 ½-inch film transport torque motor
5. Control panel and switch illuminating lamps.

Rotate the panel illumination control and ascertain that the illumination level decreases with counterclockwise rotation.

Rotate the tension control located on the chassis panel and ascertain that the tension in the 70-millimeter film over the platen increases with clockwise rotation of the knob. (The normal setting of the control is 90 on the dial.)

9.5.3 Vacuum System

Ascertain that the 9 ½-inch film is held flat against the easel when the vacuum switch is in the ON position. Position the switch at the OFF position and note that the film is released from intimate contact with the easel when the solenoid is deenergized. Position the switch in the ON position again and note that the film is pulled down instantly against the easel.

9.5.4 70-Millimeter Film Transport

Check out the 70-millimeter film transport system in the following manner:

1. Rotate the handwheel and ascertain that it rotates freely and that the film does not move.
2. Push the handwheel toward the rear and rotate it clockwise or counterclockwise, as desired. Ascertain that the film moves from left to right as the handwheel rotates clockwise, and that it moves from right to left when the handwheel is rotated counterclockwise.

9.5.5 Glow Plate

Lift the glow plate handle until the plate is in a locked position under the 70-millimeter platen. Ascertain that the plate is illuminated when in position.

Activate the PRINT switch on the control panel and note that the scan arm does not move.

Return the glow plate to the stored position by depressing the handle. Check that the plate illumination is extinguished.

9.5.6 Scan Arm

Position the scan control at the zero scale position and activate the PRINT switch on the control panel. Ascertain that the following occurs:

1. The fan motor voltage is removed.
2. The projection lamp becomes energized.
3. The arm sweeps across the platen during a total time interval of 12 seconds.
4. The PRINT switch illumination is extinguished.

At the completion of the scan arm motion note the following:

1. The projection lamp is extinguished.
2. The fan is activated.
3. The 9 ½-inch film transport system is activated.
4. The vacuum is removed from the easel by the action of the solenoids during film transport.
5. Vacuum is reapplied at the completion of the film transport.
6. The PRINT button is illuminated at the completion of the transport cycle.
7. The life counter number is increased by one count at the end of the cycle.

Position the scan control at 70 on the scale and activate the PRINT switch on the control panel. Ascertain that the same events occur as previously described except that the total time of scan should be approximately 60 seconds.

9.5.7 9 ½-Inch Film Transport

Ascertain that sufficient film is transported at the completion of the scan cycle to clear all

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exposed film from the printing area. This test may be conducted during the test outlined in the previous paragraph.

9.6 PHOTOGRAPHIC TESTS

The following tests shall be performed by project personnel and be witnessed by quality assurance personnel. The results shall be recorded on data sheet number 5 (Appendix B). The resolution values obtained shall be the geometric mean of the vertical and horizontal lines as described in MIL-STD-150. Vertical lines are defined as those lines oriented perpendicular to the direction of the scan, and horizontal lines are defined as those lines oriented in the direction of scan.

9.6.1 System Resolution

Set the slit to a 1-millimeter width. Position the negatives supplied by the contracting agency at the film plane. The test negative shall contain high contrast USAF targets positioned symmetrically within the format area. The targets shall have a minimum resolution of 228 lines per millimeter.

The targets are to be projection printed at enlarged scale on duplicating film (emulsion type 5427 or equivalent). The resolution values obtained shall be observed with a microscope and all values shall be referred to the input negative.

Primary Range

Set the instrument, using the computed values obtained from the slide rule, for the following conditions:

Altitude	Tilt Angle, degrees	Altitude	Tilt Angle, degrees
Maximum	10	Nominal	20
Maximum	15	Minimum	10
Maximum	20	Minimum	15
Nominal	10	Minimum	20
Nominal	15		

Additional Range

Set the instrument using the computed values obtained from the slide rule for the following conditions:

Altitude	Tilt Angle, degrees	Altitude	Tilt Angle, degrees
Maximum	0	Nominal	± 5
Maximum	± 5	Minimum	0
Nominal	0	Minimum	± 5

9.6.2 System Accuracy

Position test grid (supplied by the contracting agency) at the film plane. The grid shall consist of clear lines on an opaque background. The grid may be constructed of an equal rectangular pattern (about 1-centimeter square) or it may be constructed to illustrate the distortion at one particular input condition. (It is recommended that a square grid be used).

Symmetry

Position the grid symmetrically on nadir and make an exposure at the desired conditions. Measure the grid for symmetrical accuracy.

Note: Close tolerance accuracy measurements over the entire print is beyond the scope of this test specification. To obtain absolute accuracy of mensuration, the following conditions must be known:

1. Point to point accuracy of every intersection of the input grid
2. Stability of input grid material and environmental conditions at the time of test
3. Transformation equations used to determine geometry of desired reproduction (The focal length of the particular lens must be used in all computations.)
4. Method and accuracy of output measurement on a coordinatograph
5. Accuracy with which the input film was located at nadir
6. Processing techniques used on output material and percentage distortion due to processing.

Appendix A

GAMMA I RECTIFYING PRINTER SCAN ARM DRIVE

The scan arm drive is a variable velocity drive that displaces the scan arm at a predetermined angular rate. The rate of displacement is dictated by the parameters inherent in panoramic rectification (refer to Fig. A-1).

The design specifications for the scan arm drive were:

Total scan angle	80 degrees (±40 degrees from nadir)
Total scan time	10 seconds $\leq T \leq$ 60 seconds

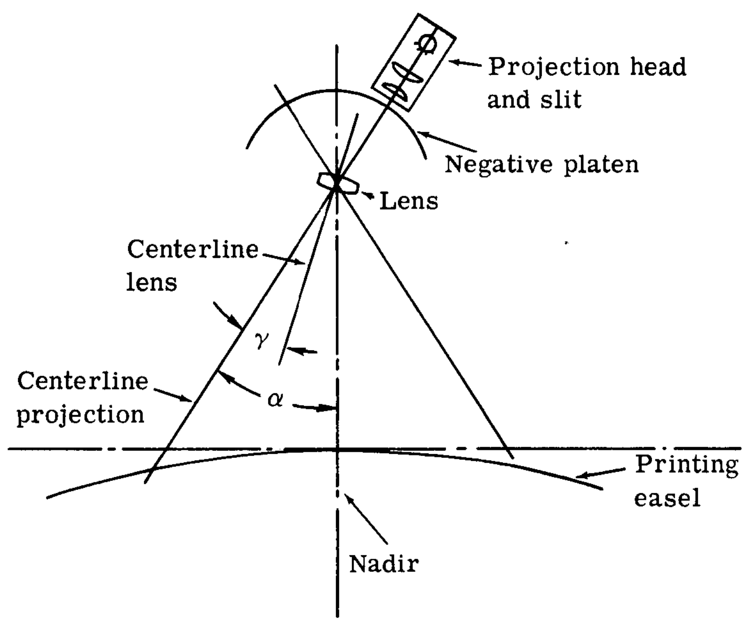


Fig. A-1 — Diagram of Gamma I Rectifying Printer

The design approach for the scan arm drive was as follows:

1. Analyze the dynamics of the scan arm and determine expressions for angular velocity, acceleration and torque.
2. Analyze the drive carriage dynamics and determine expressions for lineal velocity and acceleration.

3. Collect data and calculate the parameters needed for the drive motor.

When rectifying panoramic film by reversing the taking procedure, a falloff in light intensity is introduced during the scan displacement. This falloff is a result of the following:

1. $\cos^2 \alpha$ losses resulting from scale changes
2. $\cos \alpha$ losses resulting from the incident angle of projection.

The total reduction is the inverse product of these terms or $R = 1/\cos^3 \alpha$. The reduction during ±40 degrees scan is approximately 2.3:1, i.e., there is more than twice as much light at nadir than at the ends of the scan.

To compensate for this variance in light intensity it becomes necessary to vary the angular or scan velocity of the arm and slit such that light is imposed for a longer time at the ends of the scan and for a lesser time at nadir.

The slit velocity is a function of the intensity reduction relationship in that

$$V = \frac{V_s}{\cos^3 \alpha}$$

where V_s = momentary velocity of the slit
V = maximum velocity of the slit at nadir

The total time of scan is related to the instantaneous exposure time at nadir by the expression:

$$T = 1{,}000\ t_0$$

where T = total scan time
t_0 = instantaneous exposure at nadir
1,000 = constant determined from previous rectifier designs by integrating the projection parameters over the entire scan range as a function of time

The calculations for the derivation of this constant are as follows: Multiply α by n_2/n_2 and let $\alpha' = n_2\alpha$. Then $n_2 d\alpha = d\alpha'$ and

$$t = \frac{1}{n_2 k} \int_0^{\alpha} \frac{d\alpha'}{\cos^3 \alpha'}$$

Integrating, we get

$$t = \frac{1}{n_2 k} \left[\frac{1}{2} \frac{\tan \alpha'}{\cos \alpha'} + \frac{1}{2} \log_n \tan \left(\frac{\pi}{4} + \frac{\alpha'}{2} \right) \right]_0^{\alpha'}$$

Therefore

$$t = \frac{1}{n_2 k} \left[\frac{1}{2} \frac{\tan \alpha'}{\cos \alpha} + \frac{1}{2} \log_n \tan \left(\frac{\pi}{4} + \frac{\alpha'}{2} \right) \right]$$

Let the total time of travel, T, be 2t; then

$$T = \frac{1{,}080\ t_0}{W \text{ millimeters}}$$

When W = 1 millimeter

$$T \approx 1{,}000\ t_0$$

The equations for displacement, velocity, and acceleration can be expressed as functions of the scan angle, α. The equation of velocity as a function of α is derived as follows: Let α be the angle of scan from nadir to the centerline of the slit; then

$$\frac{d\alpha}{dt} = \frac{d\alpha_0}{dt} \cos^3 \alpha$$

where $\frac{d\alpha}{dt}$ = angular velocity of arm

$\frac{d\alpha_0}{dt}$ = maximum angular velocity of arm at nadir

Also

$$\frac{d\alpha_0}{dt} = \frac{W/F}{t_0} = K$$

where t_0 = instantaneous exposure time at nadir
W = slit width
F = focal length of the taking system
K = constant

Therefore

$$\frac{d\alpha}{dt} = \dot{\alpha} = K \cos^3 \alpha$$

The acceleration is found by differentiating the velocity

$$d\left(\frac{d\alpha}{dt}\right) = -3K \cos^2 \alpha \sin \alpha \, d\alpha$$

and dividing by dt, we obtain

$$\frac{d(d\alpha/dt)}{dt} = -3K \cos^2 \alpha \sin \alpha \frac{d\alpha}{dt}$$

where $\frac{d\alpha}{dt} = K \cos^3 \alpha$

Therefore

$$\ddot{\alpha} = -3K^2 \cos^5 \alpha \sin \alpha = \frac{d^2\alpha}{dt^2}$$

The point of maximum acceleration is found by differentiating the acceleration with respect to α and setting it equal to zero

$$\frac{d\ddot{\alpha}}{d\alpha} = 0 = -3K^2[\cos^5 \alpha(d \sin \alpha) + \sin \alpha(d \cos^5 \alpha)]$$

$$= -3K^2(\cos^6 \alpha - 5 \sin^2 \alpha \cos^4 \alpha)$$

$$= -3K^2 \cos^6 \alpha + 15K^2 \cos^4 \alpha \sin^2 \alpha$$

$$0 = -\cos^2 \alpha + 5 \sin^2 \alpha$$

$$\frac{\cos^2 \alpha}{\sin^2 \alpha} = 5 \qquad \text{or} \qquad \tan^2 \alpha = \frac{1}{5}$$

$$\tan \alpha = 0.447$$

$$\alpha = 24°5'$$

The point of maximum acceleration occurs when $\alpha \approx 24.1$ degrees.

We now have expressions for total scan time, angular velocity and acceleration of the scan arm, and the point of maximum acceleration.

Solving for maximum acceleration, we have

$$\ddot{\alpha} = -3K^2 \cos^5 \alpha \sin \alpha$$

Use W = 1-millimeter-wide slit
F = 24 inches
t_0 = 0.01 second (assume fastest scan time of 10 seconds)

$$K = \frac{W/F}{t_0} = \frac{0.03937}{24(0.01)} = 0.164 \text{ radians per second}$$

$$\ddot{\alpha} = -3(0.164)^2(\cos^5 24.1° \sin 24.1°)$$

$$= -3(2.69 \times 10^{-2})[6.34 \times 10^{-1}(4.08 \times 10^{-1})]$$

$$= -208.75 \times 10^{-4} = -0.021 \text{ radians per second}^2$$

It now becomes necessary to analyze the dynamic effects of the counterweight and projection head as well as the dynamics of the drive carriage (linear velocity and acceleration). It will then be possible to calculate the reflected dynamic loads at the drive motor. The expression for the dynamic torque for the system shown in Fig. A-2 is

$$\tau = I\ddot{\alpha}$$

where τ = dynamic torque in inch-pounds
I = mass moment of inertia about O
$\ddot{\alpha}$ = angular acceleration of scan arm

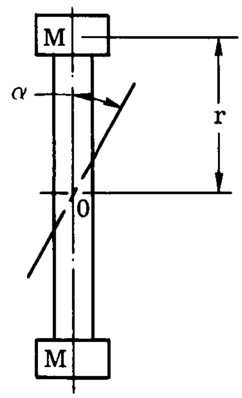


Fig. A-2 — Dynamic torque system

The expression for the moment of inertia I is

$$I = 2Mr^2$$

where M = mass weight of the projection head and counterweight
r = radius from the center of rotation to mass center

Assume that M = 40 pounds and r = 24 inches for this system; then

$$I = \frac{2(40)(24)^2}{386 \text{ inches per second}^2} = 119.4 \text{ in.-lb-sec}^2$$

The maximum dynamic torque is

$$\tau = I\ddot{\alpha} = 119.4 \text{ in.-lb-sec}^2 \times 0.021 \text{ radian per second}^2$$
$$= 2.51 \text{ inch-pounds}$$

The carriage displacement equation is obtained as follows (refer to Fig. A-3):

$$x = R \tan \alpha$$

where x = carriage displacement
R = perpendicular distance from center of rotation of scan arm to center of carriage drive roller

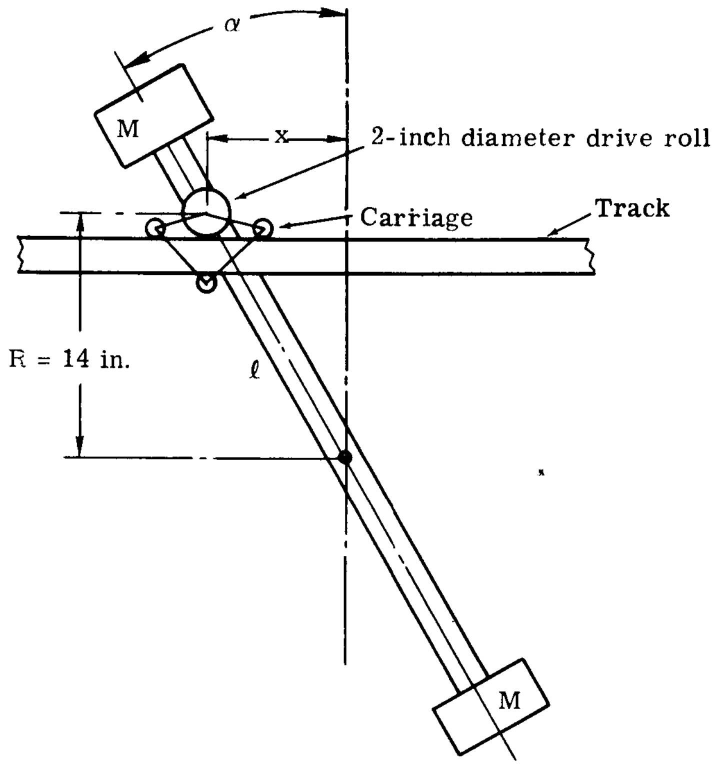


Fig. A-3 — Carriage displacement diagram

To find the velocity, we differentiate the carriage displacement with respect to time:

$$\frac{dx}{dt} = \frac{R}{\cos^2 \alpha}\left(\frac{d\alpha}{dt}\right)$$

where $\frac{d\alpha}{dt} = K \cos^3 \alpha = \frac{W}{Ft_0} \cos^3 \alpha$

Then

$$V_C = \frac{dx}{dt} = \left(\frac{R}{\cos^2 \alpha}\right)\left(\frac{W}{Ft_0} \cos^3 \alpha\right) = \frac{RW}{Ft_0} \cos \alpha = RK \cos \alpha$$

To find the acceleration, we differentiate the velocity with respect to time (refer to Fig. A-4).

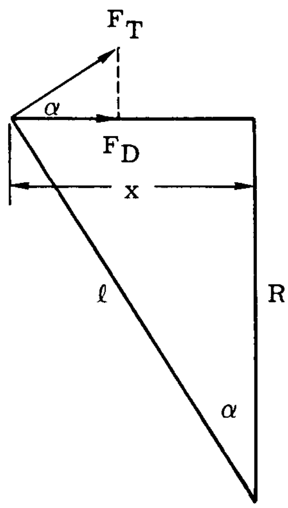
$$a = \frac{dV_C}{dt} = -\frac{RW}{Ft_0} \sin \alpha \frac{d\alpha}{dt}$$

$$= -\left(\frac{W}{Ft_0}\right)^2 R \sin \alpha \cos^3 \alpha$$

$$= -(0.164 \text{ radians per second})^2(14)(0.408)(0.413)^3$$

$$= (0.027 \text{ radians per second})^2(14)(0.408)(0.761)$$

$$= 0.117 \text{ inches per second}^2$$



R = 14 inches
T = 2.51 pound-inches
α = 24.1 degrees

Fig. A-4 — Force geometry

$$F_D = F_T \cos\alpha = \frac{\tau}{\ell}\cos\alpha = \frac{\tau\cos^2\alpha}{R}$$

$$F_D = \frac{2.51 \text{ inch-pounds } (0.91295)^2}{14} \approx 0.15 \text{ pound}$$

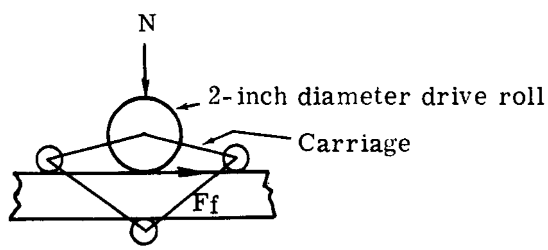


Fig. A-5 — Carriage diagram

Assume a weight of 15 pounds, including motor, housing, and gear box (refer to Fig. A-5). The force needed to drive the carriage is

$$F_c = M_c a + F_f$$

25X1

where F_c = carriage force
M_c = carriage mass
a = maximum linear acceleration
F_f = rolling friction force = μN, where μ is the coefficient of rolling friction, equal to 0.03 and N is the normal force

Then

$$F_c = \frac{15}{386}(0.12) + 0.03(15) = 0.005 + 0.45 = 0.455 \text{ pounds}$$

The total driving torque is

$$T_D = Fr$$

where F = sum of the forces $F_c + F_D = 0.6$ pound
r = radius of driving wheel = 1 inch
$T_D = 0.6(1) = 0.6$ inch-pound

Consider this as 1 inch-pound

The maximum speed of the drive roller will be found as follows (refer to Fig. A-6). The maximum linear velocity of the carriage will occur at nadir when $\cos \alpha = 1$. Therefore, the maximum velocity is

$$V_c = RK \cos \alpha = (14)(0.164)(1) = 2.296 \text{ inches per second}$$

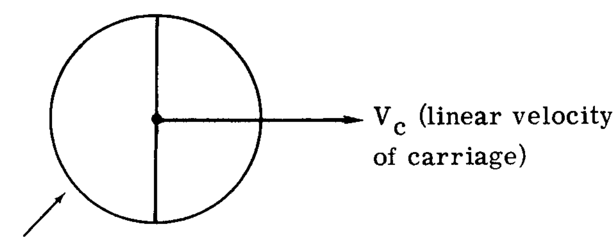


Fig. A-6 — Drive roller diagram

The angular velocity of the drive roller is

$$\dot{\theta} = \frac{2V_c}{D} = 2.296 \text{ radians per second}$$

or

$$\dot{\theta}_{rpm} = \frac{60\ (2.296)}{2\pi} = 21.9 \text{ rpm}$$

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There are two types of drives that may be used in this rectifier:

1. The first type of drive would employ a closed loop servosystem with a velocity servo driving a nonlinear potentiometer. The potentiometer would be used to control a positional servo to drive the scan arm and feedback potentiometer. The nonlinear potentiometer would have to be specially wound according to the previously derived equations. Past efforts to utilize this type of drive in rectifiers have proved relatively unsuccessful and expensive. Chatter, or instability, occurred at the positions of maximum acceleration and deceleration of the scan arm.

2. The second type of drive would employ a gear reduced, shunt wound, dc motor which received a proportional voltage by means of a variable transformer geared to the scan arm. The transformer provides an increasing voltage to the motor as the scan arm moves from the end position to nadir at which point the voltage is at a maximum; a switching method is incorporated to reverse the potentional of the impressed voltage, thereby decreasing the voltage reaching the motor. The total scan time can also be varied by changing the level of voltage impressed on the variable transformer by means of a rheostat. This overall drive system proved to be inexpensive and stable in operation. The schematic for this system is shown in Fig. A-7.

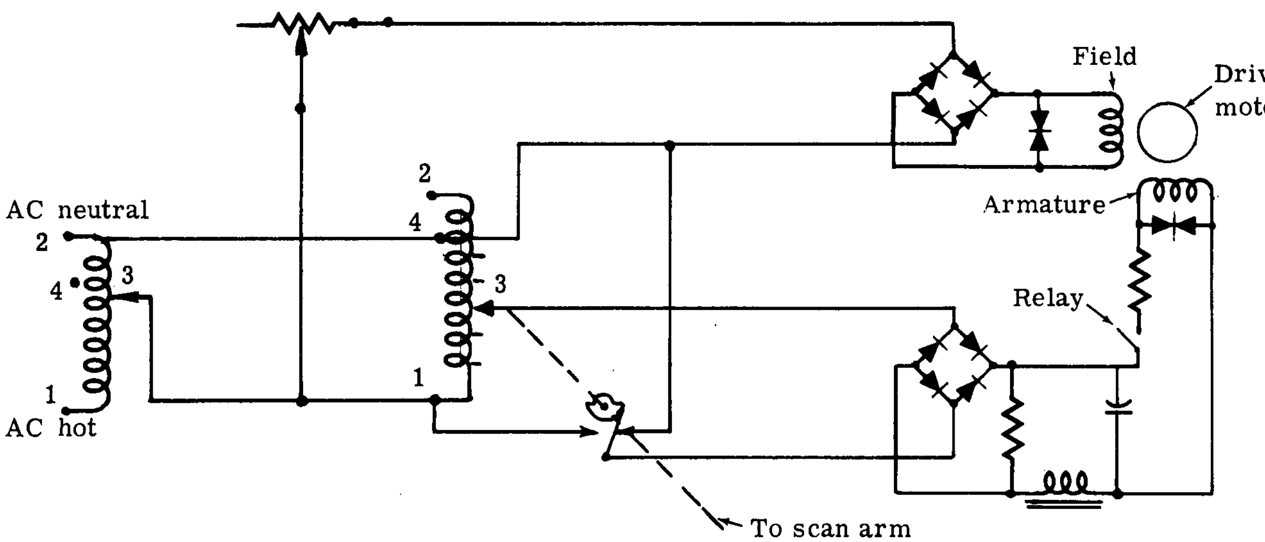

Fig. A-7 — Overall drive system schematic

The next step is to select a drive motor that will have the desired characteristics for this system, i.e., the motor must deliver a maximum speed of 22 rpm at a torque rating of 1 inch-pound at the drive roller.

From the schematic it is obvious that full power of 115 vdc cannot be applied to the motor, since the potential will be reversed during the scan. Previous tests on this type of system indicate that about 95 volts is the maximum obtainable.

Assuming a linear relationship between voltage and speed for a shunt wound motor, we obtain the relationship

$$\frac{\dot{\theta}_1}{V_1} = \frac{\dot{\theta}_2}{V_2}$$

where $\dot{\theta}_1$ = full speed at rated voltage
$\dot{\theta}_2$ = speed at reduced voltage
V_1 = full voltage
V_2 = reduced voltage

Therefore

$$\dot{\theta}_1 = \frac{\dot{\theta}_2 V_1}{V_2} = \frac{22\ (115)}{95} = 26.6 \text{ rpm}$$

The Bodine motor catalog for 115-vdc, shunt wound motors lists a 1/70-horsepower motor rated at 29 rpm at 8.0 inch-pounds of torque. This motor was selected for this application.

APPENDIX B

The following data sheets are used for inspection procedures (refer to Section 9.3.1).

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TOP SECRET

DATA SHEET 1 — MECHANICAL INSPECTION

Serial No. ________

	Accepted	Not Accepted
1. Workmanship		
• Fabrication		
• Assembly		
• Paint		
• General appearance		
2. Fasteners		
• Tightness of screws		
• Pinning and doweling		
• Setscrews		
3. Gear Trains		
• Binding or backlash		
• Lubrication		
• Burrs, metal chips, and dirt		
4. Film Rollers		
5. Light Housing		
• Tightness		
• Location		
• Boot		
• Louver		
6. Slit Mechanism		
7. V Ways		
• Binding or looseness		
• Lubrication		
8. Easel Displacement Mechanism		
• Range		
• Chatter		
9. Easel Tilt Mechanism		
• Range		
• Chatter		
10. Lens Tilt Mechanism		
• Range		
• Chatter		
• Lock		

25X1

11. Focus Cam Position Mechanism
    - Range
12. Easel Curvature
13. Component Identification

Remarks:

Rework: Not required ( ) Acceptable ( )

	Name (print)	Signature	Date
Quality assurance			
Project representative			
Contracting agency representative			

25X1

TOP SECRET

DATA SHEET 2 — OPTICAL INSPECTION

Serial No.________

	Accepted	Not Accepted
1. Projection Lamp		
• Rating		
• Cleanliness and location		
2. Projection Lens		
• Imperfection		
• Cleanliness		
• Aperture		
3. Folding Mirror		
• Imperfection		
• Cleanliness		

Remarks:

Rework: Not required ( ) Acceptable ( )

	Name (print)	Signature	Date
Quality assurance			
Project representative			
Contracting agency representative			

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DATA SHEET 3 — ELECTRICAL INSPECTION

Serial No. ______

	Accepted	Not Accepted
1. Physical Inspection		
• Cables		
• Connections		
• Terminals		
• Solder joints		
• Switches		
2. Fuses		
3. Lamps		

Remarks:

Rework: Not required ( ) Acceptable ( )

	Name (print)	Signature	Date
Quality assurance	______	______	______
Project representative	______	______	______
Contracting agency representative	______	______	______

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TOP SECRET

SPECIAL HANDLING

DATA SHEET 4 — FUNCTIONAL TESTS

Serial No. ________

	Accepted	Not Accepted
1. Power		
• Vacuum turbine		
• Projection lamp fan		
• Torque motors		
• Control panel illumination		
• 70-millimeter film tension		
2. Vacuum		
3. 70-millimeter film transport		
4. Glow plate		
5. Scan arm		
6. 9 ½-inch film transport		
7. Life counter		

Remarks:

Rework: Not required (   ) Acceptable (   )

	Name (print)	Signature	Date
Quality assurance			
Project representative			
Contracting agency representative			

SPECIAL HANDLING

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DATA SHEET 5 — PHOTOGRAPHIC TESTS

System Resolution

Serial No. ________

Altitude	Tilt Angle, degrees	Accepted	Not Accepted
Maximum	10		
Maximum	15		
Maximum	20		
Nominal	10		
Nominal	15		
Nominal	20		
Minimum	10		
Minimum	15		
Minimum	20		
Maximum	0		
Maximum	5		
Nominal	0		
Nominal	5		
Minimum	0		
Minimum	5		

<u>Accuracy:</u>

	Name (print)	Signature	Date
Quality assurance	________	________	________
Project representative	________	________	________
Contracting agency representative	________	________	________

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PROJECT HQS DOCUMENT RECEIPT		NOTICE TO RECIPIENT Sign and Return to Sender
PACKAGE NBR. S 2555		DATE SENT 25 Jan. 1965
DESCRIPTION OF DOCUMENT(S) SENT		
DOCUMENT NBR.	COPIES	ATTACHMENT(S)
COR-2620	Cy # 2	
SIGNATURE [redacted] f above document(s))		
OFFICE NPIC/[redacted]		DATE OF RECEIPT 26 Jan 65
FORM 10-63 2157		(13-25)

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