The time of development is controlled by altering the speed of the motor and, under ordinary circumstances, we are able to process three full-length films of 150 ft. each in one working day with an actual development time of approximately six minutes. Variation in line voltage is somewhat of a problem in New Zealand but we maintain constant speed by watching an aircraft revolution counter which is mounted on the top panel.

It is not economical to process less than three films in the unit on account of the quantity of chemicals involved to fill the troughs, but the quality of the negative produced is certainly worth the time involved in holding the odd film over until the next period of good weather and further flying.

DEVELOPMENT OF BAUSCH & LOMB AUTOFOCUS RECTIFIER

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BASED on the comments of several members of the American Society of Photogrammetry at its annual meeting in January 1946, the need for development of a fully automatic Autofocus Rectifier was investigated by Bausch & Lomb. This investigation revealed that the primary need for this instrument is to produce, in quantity, controlled mosaics from low-tilt aerial photographs. A second need is for changing map projections from one type of projection to another. Furthermore it appeared desirable to include military applications for such an instrument; these require use of aerial photographs taken with aerial cameras tilted to at least 20°.

In June 1946, based on preliminary investigation, a development project was instituted and operational specifications and preliminary designs of such an instrument were established. Several organizations were contacted and four types of European Autofocus Rectifiers were observed, two of which were in productive operation. Operating requirements were discussed with various individuals in both administrative and operating divisions of these organizations. Their concurrence with these preliminary specifications was obtained.

In development of such an instrument, our purpose was to simplify the mechanical principles of rectification as much as practical, and yet to obtain an exact mechanical solution of rectification in the design for manufacture of a fully automatic Autofocus Rectifier having operating speed and convenience. Thus, the operating cost per rectified print or map projections where the volume of prints is large could be kept at an operational minimum. This is in line with our development policy. As in the Multiplex Mapping System, the effort is to develop optical solutions of photogrammetric problems which, in mechanical design are as simplified and maintenance free as possible, and at the same time will meet the exact theoretical and practical operational specifications of photogrammetric instruments and of mapping organizations.

A comprehensive investigation of the autofocus rectification of aerial photographs was instituted to study past developments, using among others the following references in literature which are readily available to photogrammetrists.

"Rectification of Tilted Photographs," J. H. Dickson-Photographic Journal, Section B: March–April 1945.

"Essays on Photogrammetry," O. VonGruber 1932, Chapman & Hall Ltd.

"The Rectification of Tilted Aerial Photographs," A.M.S. Bulletin No. 21 PHOTOGRAMMETRIC ENGINEERING 12, (3), September 1946.
"Engineering Applications of Aerial & Terrestrial Photogrammetry." B. B. Talley, Section 6, 1938.
"MANUAL OF PHOTOGRAMMETRY, Chapters 2 and 10, Preliminary Edition 1944.

Ample coverage of the mathematical principles of rectification is contained in these references, so the scope of this paper is only to invite attention to optical and geometric properties of specific points in a diagram of the design of the Bausch & Lomb Autofocus Rectifier (Figure 1). In the various mathematical derivations of rectification principles, the basic properties of these points were often not clearly described. These are included herewith as an aid to understanding the principles which are incorporated in this instrument. The diagram also shows with arrows the direction of movement of the various parts of the rectifier named in the diagram. The following is a table of the essential relationships and the definition of terms used in the diagram.

f = Focal Length of Aerial Camera Lens

t = Tilt of the Aerial Camera

N = Nodal Point Separation of Rectifier

F = Focal Length of Rectifier Lens

M = Long Arm or Peaucellier Inverter

L = Short Arm of Peaucellier Inverter

h = Principal Distance of Rectified Photograph

$M^2 - L^2 = F^2$ Peaucellier Inverter Relationship

$\frac{\tan \beta}{\tan \alpha} = M_0$ Optical Magnification

$\frac{\sin \beta}{\sin \alpha} = M_s$ Scale Change of Aerial Photograph

$XX' = F^2$ Newton Optical Conjugate Formula

$$\frac{X'}{F} = \frac{F}{X} = \frac{b}{a} = \frac{\tan \beta}{\tan \alpha} = M_0$$

$$F \sin t = f \sin \beta = h \sin \alpha$$

$$\frac{h}{f} = \frac{\sin \beta}{\sin \alpha}$$

$$\frac{F}{f} = \frac{\sin \beta}{\sin t}$$

$$\frac{F}{h} = \frac{\sin \alpha}{\sin t}$$

$$d = \frac{f}{\tan t} - \frac{x}{\sin \alpha}$$ Offset of Principal Point

The functional diagram demonstrating the principles of the Autofocus Rectifier (Figure 1) presents actual members of the instrument by solid lines.

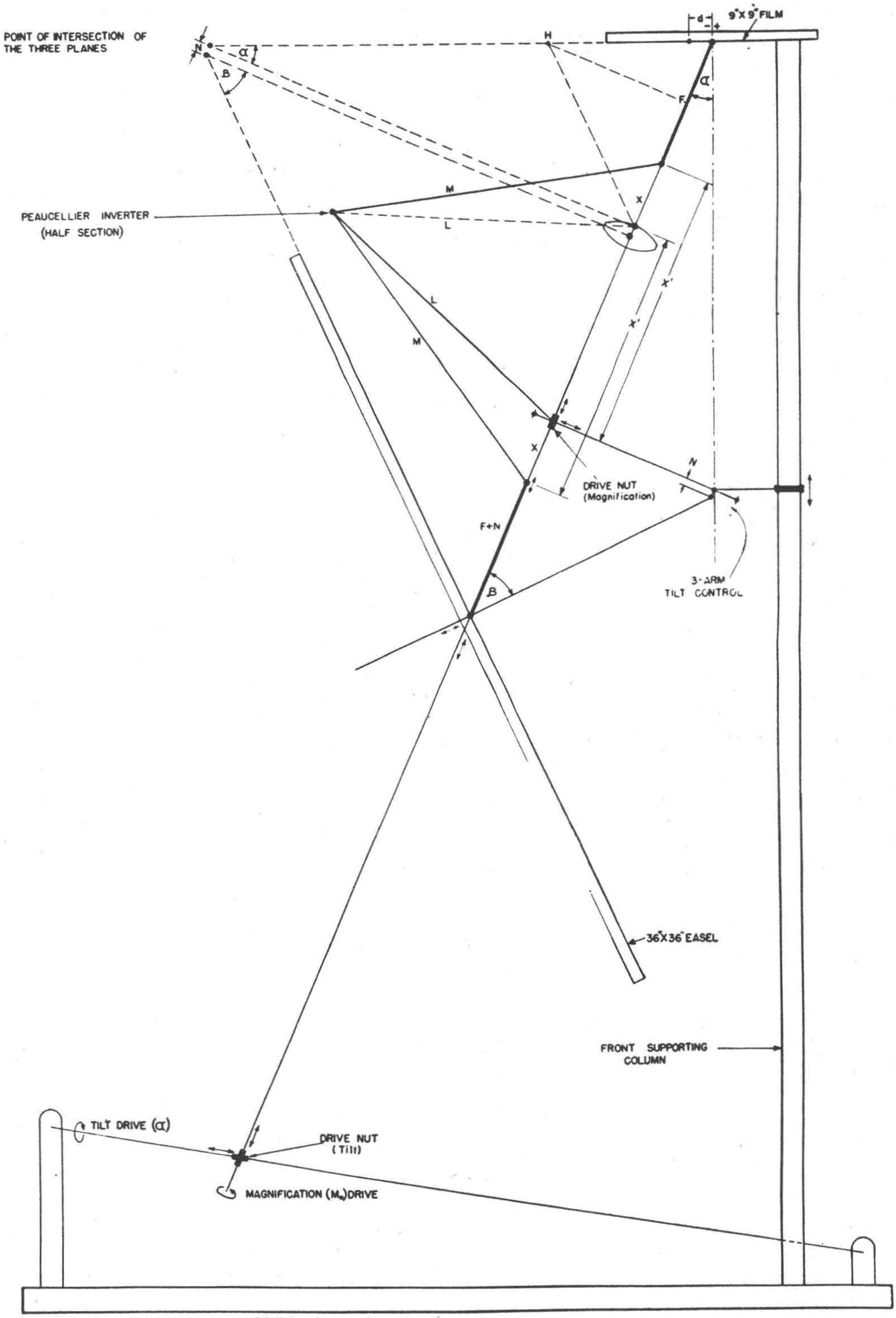

FIG. 1. Principles of Bausch & Lomb Autofocus Rectifier.

Dotted lines, extended if necessary, are used primarily to indicate planes perpendicular to the plane of the diagram. The basic photogrammetric requirements of the instrument are: first, that, for critical focus, the conjugate tilted planes of lens, easel and film must always intersect in a common line in space (i.e. of course, if nodal point separation of the lens were zero). Second, the Newton conjugate relationships for all image and object points shall be maintained; and the relative perspective relations in image and object shall be maintained by offsetting the film. Consideration is given in design to the fact that separation of the lens nodal planes exists.

The following properties of various components of the instrument shown in the diagram are of importance. Every photographic film negative from a tilted camera has a horizontal line represented by point (H) at a distance "$f/\tan t$" from its principal point. (H) is a point, since the line is maintained by film rotation, perpendicular to the plane of the diagram. This point (H) is not necessarily within the film image but is located in the film plane (extended) of the rectifier. This horizon line is also the line where parallel lines in a tilted image meet. (i.e. vanish). An object ray from this horizon line to the object nodal point of the rectifier lens emerges from the image nodal point of the lens parallel to the easel. Thus the rectified image on the tilted easel without any residual tilt is produced without an horizon line, an often overlooked condition for true rectification; that is, a rectified image on the easel whose horizon line is at infinity. This latter fact from optics also requires that the horizontal line of the film plane lie in the image focal plane of the rectifier lens which firmly establishes its unique position necessary for exact rectification. This focal plane is represented by a dotted line from "H", parallel to the lens plane. It is to be noted also that from tilted camera conditions, the distance in the film plane from the horizontal point (H) to the principal point of the camera film ($f/\tan t$), is usually different from the distance ($X/\sin \alpha$) from (H) where the optical axis of the rectifier intersects the film plane. This difference, little understood by many producers of so-called controlled mosaics, is known as the film offset "d" which is also a condition of exact rectification to be met in production, thus: $d=f/\tan t - X/\sin \alpha$. The mathematical relationships of an Autofocus Rectifier, as shown in Figure 1, are derived entirely by right triangle relationships.

The only relationship not at once obvious, and not readily available to photogrammetrists generally, is the derivation of the relationship of the fixed arms of the Peaucellier Inverter (or Inversor as it is sometimes named). This relationship is based on right triangles and is as follows:

$$M^2 - \left(\frac{X+X'}{2}\right)^2 = L^2 - \left(X' - \frac{X+X'}{2}\right)^2$$

Then:

$$M^2 - \left(\frac{X+X'}{2}\right)^2 = L^2 - \left[X'^2 - XX' - X'^2 - \frac{(X+X')^2}{2}\right]$$

Since by Newton's formula:

$$F^2 = XX'$$

Then by cancellation of equal terms and substitution:

$$M^2 - L^2 = F^2$$

For further mathematical analysis of this subject see "The Rectification of Tilted Aerial Photographs," Ph. Eng. September 1946.

Based on the above principles and operational considerations, the following primary design features were developed.

1) *Film and Light Source Housing.* A considerable portion of the instrument weight and several functions of the mechanical control system in the design of the Autofocus Rectifier are parts of the film housing. These functioning parts are the 360° swing rotation of the film stage, the ±90 mm. transverse and lateral displacements of the film stage, the film location and pressure plate control, the cooling equipment, light tight bellows support, the electrical wiring and light source and the motion scales. Consequently, unlike previous rectification, it was found best to stabilize the film plane in a horizontal position by direct support from the base of the instrument. This led to the design in which the lens axis is tilted; and in which the easel is tilted on an axis mounted perpendicular to, and moving along this axis of projection. By stabilizing the film plane horizontally, it is also possible to keep the overall height of the instrument under 6 feet. The easel plane is maintained at practical height limits above the floor, for the range at which the instrument is used. In fact it became evident in use that having the easel low for enlargements, and high for near unity magnification is an operating convenience.

2) *Magnification and Tilt Control Mechanism.* The mechanisms considered to control magnification were the Pythagorus Inverter, cam controlled mechanisms right angle inverter, and the Peaucellier Inverter. Taking into account the range of magnification specified, the lens focal length, the type of tilt control to be used, and the need to control back-lash without use of counter weights, the novel form of the Peaucellier Inverter (Figure 1) was designed and used. On other instruments, this type of inverter has been used with heavy counterweights to drive the lens directly and control the film plane with respect to a fixed easel axis.

In this design (Figure 1), a novel easel tilt control was also developed in which each arm is less than 24 inches long. It is driven in part by the inverter and in part by the lens axis tilt drive, to maintain the easel at the correct tilt positions with respect to the lens and film planes. To save weight, the entire tilt and magnification mechanism is counter weighted by the easel itself to such an extent that additional weight of an operator leaning on the easel would not change its vertical position by more than 0.1 mm. (the least count on the conjugate distance scales used). The lens is not supported directly by the inverter, (See Figure 2 for a sketch of this mechanism) but is driven by a separate long hollow screw which also slides on, and is keyed to a separate shaft (b) parallel to the inverter spindle (c). This shaft (b) also is geared to inverter spindle (c) and revolves to keep the lens the same distance $(F-X')$ from the easel as the drive screw of the inverter spindle keeps the drive-nut (d) from the film plane, thus maintaining the film, lens, and easel distances conjugate and also maintaining critical focus at all tilts within specified limits. Adjustments for factory assembly to the specific focal length of the lens are incorporated in the design.

The tilt control mechanisms comprise a lever (e) which is mounted on the axis of the easel and is normal to its surface, a lever (f) which is fastened to the drive unit (d). The keyway machined into it is always at right angles to the axis of the drive shaft (c), and thereby, is normal to the lens axis. Both levers are linked together by a sleeve (g), which is governed by the position of the nut (d) and the tilt of the lens axis and which can slide upon the vertical shaft (h). Shaft (h) represents one of the front columns of the instrument, as shown in Figure 3.

3) *The Illumination System.* The need was expressed, by operators of Euro-

pean rectifiers, for as much additional uniform visual light as is practically possible, and also for the height limitation of the instrument. Consequently, standard fluorescent tube illumination was used which, besides extra light and life time, has the added advantage that the film plane is kept relatively cooler for the same amount of visual light. The control of the variation in projected light is regulated in operation by hand dodging together with a lens shutter with regulated speeds.

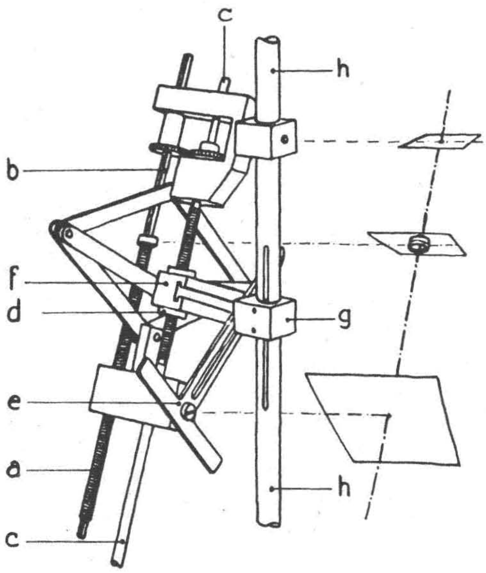

FIG. 2. Sketch of Mechanism of Easel.

4) *The lens.* The special Wide Angle Metrogon lens including the film supporting plate was designed by Bausch & Lomb Optical Co. for rectification at finite magnifications. For rectification work, it has negligible distortion and high resolution. Its wide field and short focal length form the optical basis by which low height and weight specifications were met, in conjunction with the wide ranges of magnification and tilts.

Considering its short focal length and wide angle design for use at finite magnification, its performance has proven excellent in operation for compilation of controlled mosaics.

For further details of design, the following tabulations of the major specifications is added.

BAUSCH AND LOMB
Autofocus Rectifier
Tabulation of Major Operating Specifications

Table of Limits	*Not over*	*Not less than*
Height	72″	—
Weight	800 lbs.	—
Floor Space	6′×6′	—
Negative Size	$9\frac{1}{2}''\times9\frac{1}{2}''$	—
Film Spool Capacity	450 exposures	—
Easel Size	—	—
Metrogon Focal Length	5.6″	5.4″
Metrogon Lens Speeds	f/6.3	f/32
Illumination on Easel (At unity Magnification)	—	4 lumens/sq. ft.
Average Film Exposure	30 seconds	—
Film Temperature (90°F. ambiant)	125°F.	—
Electrical Power Supply	105 V.–60 c.	125 V.–60 c.
Table of Ranges		
Motion	*Range*	*Least Count on Scale*
Swing (Rotation of Film)	Thru 360°	30′
Lateral Displacement	±90 mm.	0.1 mm. (Veeder Counter)
Transverse Displacement	±90 mm.	0.1 mm. (Vernier)
Magnification (Optical) (Ratio of Conjugate distance scales)	0.55×* to 4.0×*	0.1 mm. (Verniers)
Easel Tilt (β)	33°* to −10° (approx.)	5′ Vernier
Lens Tilt (α)	33°* to −5°*	5′ Vernier

* Automatic Stops (Electrical cutoff)

Table of Camera Tilt for Typical Camera Focal Lengths
(To be used with any focal length camera within limits)

Camera Focal Length f	Scale Ratio M_s	Camera Tilt t	Lens Tilt α	Easel Tilt β	Film Displacement d
6″	0.6×	20.8°	33°*	19.1°	−75 mm.
	1.0×	36.5°	33°*	33°*	−46 mm.
	3.5×	36.5°	8.9°	33°*	−10 mm.
8¼″	0.6×	26.0°	29.1°	17.0°	−90 mm.*
	1.0×	46.0°	28.6°	28.6°	−90 mm.*
	3.5×	54.8°	8.9°	33°*	−70 mm.
12″	0.6×	25°	18.8°	11.2°	−90 mm.*
	1.0×	33°	14.5°	14.5°	−90 mm.*
	3.5×	40°	4.8°	17.1°	−90 mm.*

* In some cases, these limits could be increased with minor design changes.

The use of the instrument in photogrammetry is to produce controlled mosaics. Two basic types of controlled mosaics are:

a) Controlled mosaics composed of tilt-free photographs which have been rectified to control points of common horizontal reference plane. The points of the photographs are consequently projected into their true parallax position on this reference plane. These rectified photographs are the nearest possible approach to a scaled orthogonal map. There is no continuity of features between adjacent photographs due to relief parallaxes. However, this is the only type of controlled mosaic in which the position of objects in the mosaics can be consistently and accurately located on an associated topographic map, since rectification is accomplished to a uniform horizontal reference plane.

b) Control mosaics composed of photographs which are rectified to the best average tilted plane through at least four control points for each photograph. This offers the closest practical approach to continuity of features along the cutting line of adjacent photographs; but such mosaics do not permit consistent and accurate location of objects on an associated topographic map.

Procedures for making either type of controlled mosaic require precise ground control points of known height and elevation of at least four per photograph, marked on a template sheet. This template is laid on the easel to which the projected image of the film is adjusted instrumentally, prior to making the photographic print, by using the five instrument controls available. It is to be noted that these templates with control points for both types of controlled mosaics can be obtained from plotting the control points on the templates directly under the Multiplex projector in the stereoscopic terrain model which is properly oriented. Scale magnification of two to three times the film scale is available in using the Multiplex Projector. After the template is placed on the easel, the image of the film negative is adjusted to fit the template control points by the use of the five instrument controls. These five required controls are the optical magnification (M_0); the tilt (α); film rotation, and two film offsets, one (d) perpendicular and one parallel to the axis of the instrument tilts; this latter motion although theoretically not necessary, is practically useful in photographic rectification practice, particularly for the type (b) mosaics mentioned above. It is also useful for other types of one and two step rectification processes in changing map projections.

The first Bausch & Lomb Autofocus Rectifier (Figure 3) was manufactured and then exhibited by the Company in January 1948 at the A.S.P. meeting in

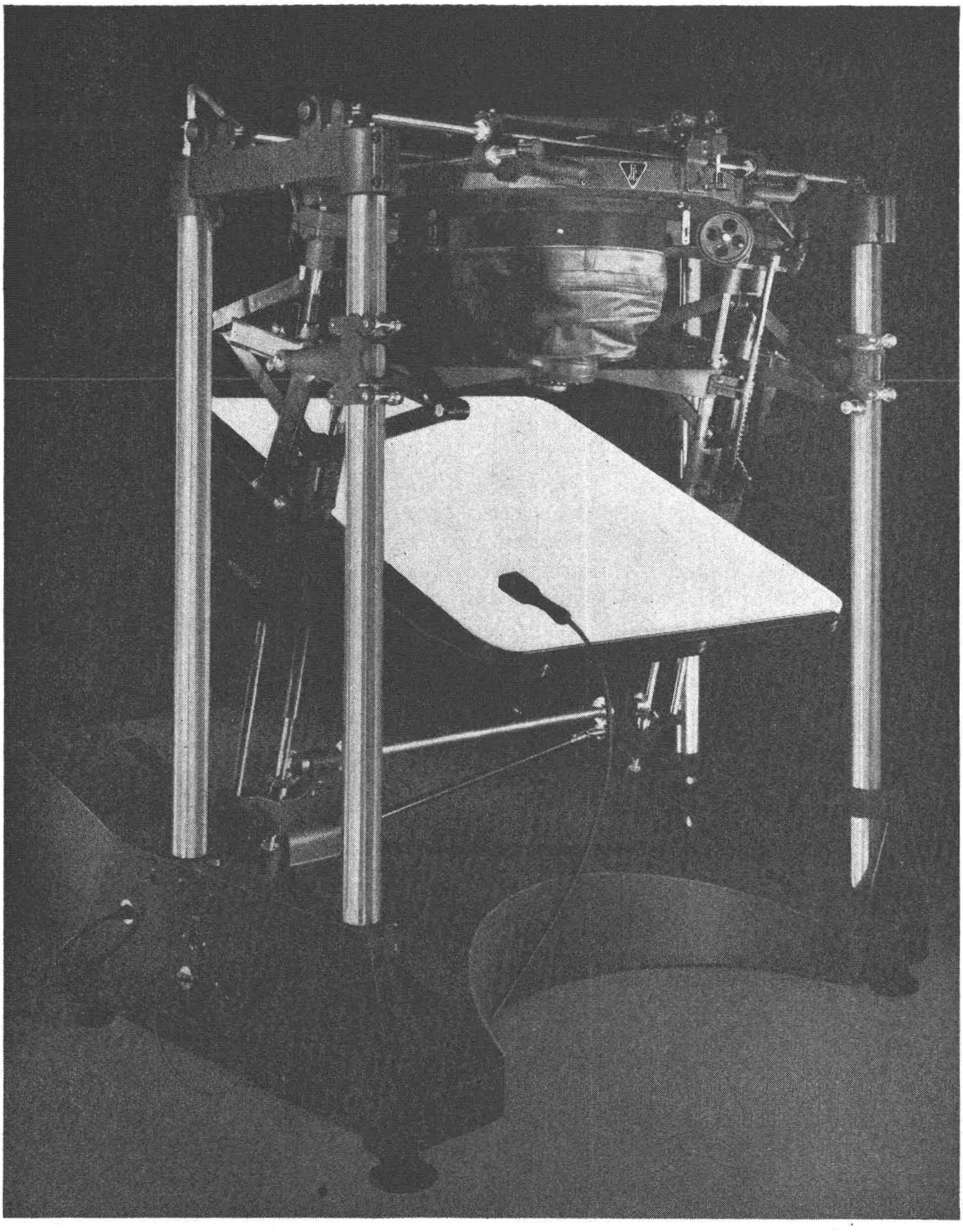

FIG. 3. The First Bausch & Lomb Autofocus Rectifier.

Washington, D. C. It was subsequently delivered to the Engineer Research and Development Board, Fort Belvoir, Virginia where it is being used under operating conditions. Among the suggestions from the Engineer Research and Development Board which will be used are that the swing drive will be mechanically instead of electrically operated, and that foot operated electrical control of the tilt and magnification drives will be made available as optional equipment on the first lot of instruments soon to be manufactured.