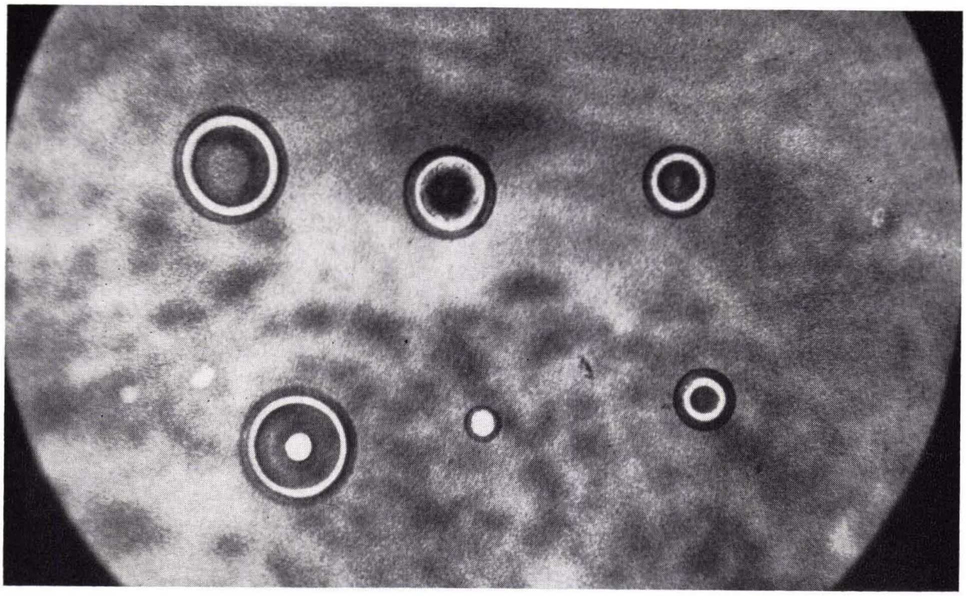

FRONTISPIECE. Samples of the six types of marks produced with the Variscale Stereo Point Marking Instrument.

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Variscale Stereo Point Marking Instrument

Tests show some significant results obtained with this unique device.

(*Abstract on page 1262*)

INTRODUCTION

IN THE FIRST PART of 1963 the Army Map Service submitted requirements to GIMRADA for an accurate marking instrument to transfer image points on photographs with large changes in format size and scale. From these requirements came the Variscale Stereo Point Marking Instrument, designed and built by Bausch and Lomb, Inc. This is the first marking instrument to provide a point transferring capability for analytical aerial triangulation for both equal- and unequal-scale photographs. It contains many features, some of them unique, such as a variety of reticle and mark sizes with calibrated adjustment means, image rotators, phoria adjustments, and parallax read-out, to provide a highly precise marking capability. Two instruments were built, the first delivered to the Army Map Service in October 1965, and the second to GIMRADA in April 1966. Engineer tests have been performed on the second instrument and this paper discusses its significant results. A description of instrument design and operation is also provided.

* The name of the organization has been changed to USAE Topographic Laboratories.

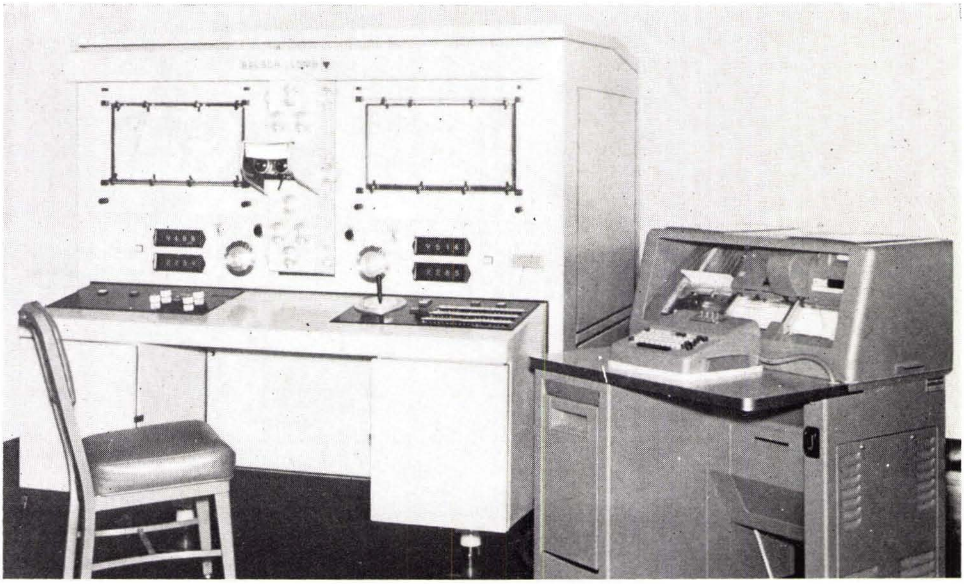

FIG. 1. The Variscale Stereo Point Marking Instrument manufactured by Bausch & Lomb, Inc. for GIMRADA.

DESCRIPTION OF INSTRUMENT

The Variscale Stereo Point Marking Instrument (Figure 1) is an optical-mechanical instrument to select and mark conjugate image points on two aerial photographs which can have large variations in scale and format size. It contains two tables, one located above the other, each with *xy*-dependent carriages. The two photoholders accept any size photograph up to 9×18-inch image format on either film or glass plates with thicknesses up to one-half inch.

The bulkiness and weight of the largest possible input material ($9\frac{1}{2}\times18\frac{1}{2}\times\frac{1}{2}$-inch glass plate) requires the use of an auxiliary stage to load the photoholders. This stage, located on the back of the instrument, is raised or lowered to each table level to accept its respective photoholder. By means of an auxiliary base on rollers the photoholder is moved off the table on the auxiliary stage. Each photoholder contains: reference marks to position each photo to the center of the scanning area; vacuum and acetate masks to hold each photo, and three leveling screws to bring the photo emulsion to the correct scanning and marking plane.

The drive system controlled by a joystick allows table travel in any direction at speeds from 0.5 mm to 25 mm per second in the coarse mode, and at speeds from 2 to 100 microns per second in the fine mode. Each carriage has a *coarse* measuring capability with a resolution of 0.1 mm and a *fine* measuring capability with a resolution of 1 micron. The latter functions only over small distances and is used only for the parallax-removal operation.

The optical system consists of two identical optical trains, each with continuous magnification from 2× to 32× in two steps, 360-degree image rotators, *x* and *y* phoria adjustments, and a binocular viewer with 5× magnification eyepieces, focus control, and interpupilar distance adjustment. An optical switch is also available to interchange the two optical paths as viewed through the binoculars. A reticle turret mounted on a small *xy*-carriage is located between the eyepiece and zoom lenses. A choice of six different reticles (Frontispiece) can be inserted in the optical train and aligned to the produced mark. The marking turret, consisting of six different dies and a flagging die, is located between the objective lens of the optical train and the input material.

Each die, after lowered on the photographic emulsion, is heated for a fraction of a second to mold a mark in the emulsion. Its design was discussed in a paper presented at the 1966 ASP Annual Meeting, titled "The Capacity-Discharge Method of Point Marking" by Mr. Martin Dvorin of Bausch and Lomb, Inc. The first mark (lower left in the Frontispiece) is a 50-micron dot in the center of a 200-micron circle. The second is a 50-micron dot and the third through the sixth marks are 75, 100, 150 and 200-micron circles. The flagging mark is a 2-mm circle (Figure 2). The reasons for the different dies are to determine, first, what type is most suitable in production use on compilation instruments in terms of accuracy in alignment and ease of identification, and secondly, the advantages of marking with sizes relative to the scale of the input over a limited scale range, so that the marks are seen in stereo with the surrounding image area.

On the front of the instrument are: photo-point locators to indicate the viewed image area with respect to the whole photograph; coordinate displays showing either *coarse* or *fine* coordinates; the joystick to drive either or both tables; and controls for illumination and for the marking system. In addition there are 60 digiswitches for point-identification data which, together with the *coarse* coordinates of the marked point, are automatically read-out on an IBM Card Punch located next to the instrument.

Description of Operation

The two photos are loaded in sequence on the auxiliary stage and positioned on the two tables. Photo prints are placed on the photo-point locators, and images scales equalized using the highest possible magnification compatible with image quality. The magnification controls are then locked. Next the desired reticle and mark die are placed in position and a test mark is made. The reticle is aligned to the mark produced using additional magnification (5×) provided by an auxiliary telescope positioned over the binoculars to obtain high accuracy in calibration. The magnification of either optical train cannot be changed at this time because it would create errors in the registration of reticle to mark. This means that the instrument is designed to handle vertical photography. (Oblique photography can be marked; however, it is a slow operation because constant recalibration of reticle to mark is required for each point in at least one optical train, and excessive operator eye fatigue and reduction in accuracies of conjugate point determination.)

Abstract: *The Variscale Stereo Point Marking Instrument fills in the special need for accurate point marking at high operation speeds on photographs with different scales and formats. The results of engineer tests show that: no visible error exists in the marking system; that calibration errors are in proportion to magnification; and that the scale ratio between two photographs of similar quality and resolution seems to have no effect on the accuracy of parallax removal. The tests also show that apparent image motion as seen by the operator must have a sufficient speed range to allow accurate parallax removal.*

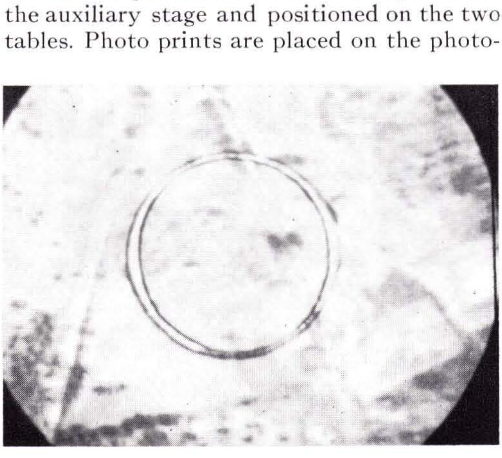

Fig. 2. Sample of the flagging mark which is produced 2000 microns in diameter.

The operator is now ready for the marking operation. He can mark either both conjugate points or transfer from a previously marked point to its conjugate position. For each point he aligns one table on the desired point and eliminates parallax using the second table with the aid of image rotators and the visual displays of the *fine* coordinates. The selected marking die(s) is (are) placed in position and the point(s) marked. Then the *coarse* coordinates and photo identification data are read-out on the card punch, one card per point per photograph.

Test Results

The engineer tests have dealt primarily with the stability and accuracy of the marking system, the registration accuracy between reticle and marking system, and the repeatability of parallax removal or accuracy of conjugate-point determination on equal and unequal-scale photographs.

POINTING ACCURACY

The first test dealt with the pointing accuracy of the instrument, that is, the accuracy with which an operator can align a selected reticle on a well-defined image point. Test material was a grid copy on which line intersections with a line width of 20 microns were used as targets. Using the auxiliary telescope on the binoculars to increase pointing accuracy, tests were made with magnification settings from 2× to 32×, which together with the 5× magnification of the telescope increased these from 10× to 160× magnification. Ten observations were made on each of several targets and the standard deviation computed. The results are listed in Table 1. The results show that accuracy of repeated settings on a well-defined point is a function of magnification, and that the optics have the quality and the tables the sensitivity to achieve these high accuracies.

REGISTRATION ACCURACY

The second test was to determine the accuracy of registration of the reticle turret with the marking system, or stated in another way, the accuracy of alignment of a compatible reticle on the selected mark at all magnifications. Only one or two reticles can be used with each mark at selected magnification settings because of the different mark sizes and because the size of the reticle at the image plane changes with magnification. With the aid of the auxiliary telescope the reticle was aligned on each mark at magnifications from 10× through 160× at several intervals. The reticle was then aligned on a grid line intersection and a mark made. The grid was then measured on a Mann Comparator at 80× optical magnification to determine the difference between the center of the mark and the grid line intersection.

The standard error was computed from these differences and the results listed in microns in Table 2. The results show that the first three types of marks produced give better registration accuracies over a larger magnification range than the last three types of marks. The errors are primarily interpretation errors and those at the lower magnifications are nearly all in one direction, showing a constant or index error, which is not significant if that mark size is used for all points measured on the photo in one operation.

TABLE 1. SUMMARY OF TEST RESULTS OF POINTING ACCURACY

Total Magnification	10×	20×	40×	80×	160×
Sx	6.5	3.0	1.8	1.4	1.4
Sy	7.0	3.0	1.4	1.4	0.2

TABLE 2. SUMMARY OF TEST RESULTS OF REGISTRATION ACCURACY

Total Magnification	10×		40×		160×	
	Sx	*Sy*	*Sx*	*Sy*	*Sx*	*Sy*
Marking Die No. 1	2.6	6.6	1.4	1.6	0.6	0.4
2	—	—	0.6	2.4	0.8	0.4
3	9.4	4.0	1.4	1.0	0.8	1.0
4	5.2	8.4	7.4	7.6	0.2	1.0
5	5.0	3.0	5.3	3.3	0.5	1.0
6	4.0	8.0	6.0	4.0	1.2	1.1

STABILITY

The third test was to determine the accuracy of repeatability of the marking system to make a mark at selected positions, which defines the stability of the system. Each mark was tested at maximum magnification (160×) using the auxiliary telescope. At that magnification differenses of 1 or 2 microns are noticeable between the mark produced and the compatible reticle by an experienced operator. Tests were made on both grid line intersections and regular photographic imagery. By visual inspection no errors were noted between the reticle and the mark for each of 50 trials made for each die. Tests were also made on a step wedge to determine any change in size and line width of each mark on different densities.

The marks were measured on the Mann Comparator and the results show differences in mark size and line width of between 1 and 2 microns for each die. The marks have good contrast because most of the emulsion has been pushed away or compressed at the bottom of the circular valley-shaped mark. It is most prominent on high-density emulsion but is still readily visible on low-density emulsion. The excellent results obtained from the above listed two tests were made possible because of compatibility between reticle and mark, the sharp contrast and good concentricity of the marks, the better-than 10 lines per millimeter per power resolution of the optical trains (better than 300 lines per millimeter have been observed at 32× magnification on a 600-lines-per-millimeter resolution target), and the use of a auxiliary telescope. The compatibility between reticle and mark was made possible by using circles,

TABLE 3. SUMMARY OF TEST RESULTS OF PARALLAX REMOVAL REPEATABILITY

Scale Ratio		16:1	7:1	3:1	1:1
Large Scale Table Magnification		2×	4×	9×	20×
Pt. 1	*Sx*	5.3	6.0	4.1	1.6
	Sy	6.3	7.4	3.3	2.8
2	*Sx*	13	7.6	4.4	1.5
	Sy	12	3.5	1.6	1.2
3	*Sx*	8.0	6.1	1.2	0.7
	Sy	6.0	9.3	3.2	0.8
4	*Sx*	11.0	3.2	2.7	1.3
	Sy	11.0	3.5	3.7	1.6
Small Scale Table Magnification		32×	28×	28×	23×
Pt. 1	*Sx*	1.2	1.7	1.6	1.0
	Sy	1.3	1.7	1.4	1.0
2	*Sx*	0.3	1.3	1.1	1.2
	Sy	1.0	0.8	1.5	1.2
3	*Sx*	0.3	1.6	1.1	1.2
	Sy	1.0	1.2	1.6	0.0
4	*Sx*	1.2	1.0	1.0	1.1
	Sy	0	1.2	1.7	0.8

circles with a dot in the center or two concentric circles for the reticles, thus providing an optimum *splitting the difference* capability in aligning circular reticles on circular marks.

PARALLAX REMOVAL ACCURACY

The last series of tests were to determine the accuracy with which an experienced operator can determine conjugate imagery on equal and unequal scale photography. The latter are unique in that very little data are available up to date on characteristics of this type of stereoviewing.

On equal-scale photography the highest desired magnification for viewing normal aerial photographs was approximately 24×. At this magnification an experienced operator can obtain standard deviations in repeated trials of parallax removal of between 1 and 3 microns on optimum quality imagery. This accuracy is reduced using either poorer quality imagery or a less experienced operator.

Several scale ratios were selected to test accuracy of parallax removal on unequal-scale photography. For each selected scale ratio four points were selected in the overlap area and ten trials of parallax removal made separately in x and y using both tables in sequence. The standard deviation was computed for x and y for each point for each selected scale ratio and the results listed in microns in Table 3. The heading *Large Scale Table* and *Small Scale Table* signify the table containing the particular scale photograph which was used to remove parallax.

The results show accuracies comparable to the equal-scale tests using the table with the smaller scale photograph for parallax removal. They also show that the accuracies obtained using the larger-scale table for parallax removal are much lower at the higher scale ratios and increase as the scale ratio decreases. The reasons for the difference in accuracies between the two tables is due to the limitation in speed of the *fine* drive system. A certain speed of apparent image motion is required to obtain good repeatability in parallax removal. The larger-scale imagery moved too slowly at maximum table speed (100 microns per second), especially at the larger scale ratios. A modification to the *fine* drive system to increase maximum speed at least three times should greatly increase the accuracy of parallax removal with the large scale table.

Speed and ease of operation features, especially the photo-point locators, and good quality optics make this a versatile, rapid, and precise marking instrument.