K.E.K. STEREOSCOPIC PLOTTER

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BEFORE discussing the principles, merits and workings of the K.E.K. Stereoscopic Plotter, I should like to give credit to the Forest Service, Region 2, Denver, Colorado, and my coworkers in the designing of this instrument, Mr. John W. Elliott and Mr. Philip B. Kail, and to mention the fact that the name "K.E.K." is the first letter of each of our names.

From earliest infancy, the K.E.K. Stereoscopic Plotter has been a stepchild of poverty. Strangely enough, however, its maternal parent is that prolific old dame, Necessity, the traditional "Mother of Invention," who has also given birth to progeny of far greater renown, such as the Multiplex, the Stereoplanigraph, and other equally famous names that command respect wherever photogrammetry is known. Fair to look on they are, too, particularly in glamorous and expensive catalogs, but with more than a trace of snobbery and haughty disdain in the presence of slim purses; or so, at least, they appeared to a group of Forest Service engineers and photogrammetrists who would gladly have courted the proud beauties if the necessary funds could have been found.

Purses, like people, seem to be by nature either lean or fat, and so it is with Forest Service mapping allotments; they have always been decidedly slim. This agency has been entrusted with the administration of vast areas of the nation's wild lands, and therefore is primarily a map user, not a map maker. Had it not been that the task of mapping these lands was so enormous that the mapping agencies of the Government had never been able to make more than a good start, the Forest Service would very likely have had occasion to undertake only minor topographic surveys of small areas such as building or dam sites. But modern land management of large areas demands administrative maps on which may be superimposed accurately a wide variety of resource and allied data, and since modern land-use planning, to be worthy of the term "modern,"

* Jasper E. King was born in Banners Elk, North Carolina, on July 30, 1898. He received his elementary education in public schools in North Carolina, Oklahoma, Texas, and Florida, and later attended Georgia Tech. and George Washington University.

His first position was with the United States Geological Survey in 1917; two years later he passed the Civil Service examination for Junior Engineer, and in the same year was appointed Junior Topographic Engineer in the Geological Survey.

From July, 1919 until October, 1921, King served as a member of a Geological Survey party assigned to topographic mapping of the Dominican Republic. In 1923 he resigned his position with the Geological Survey.

For the next two years King made timber surveys for the U. S. Forest Service in Alaska. The timber survey work was followed by a period of free-lance engineering concerned principally with mining property and hydro-electric development in northern Ontario and the Hudson Bay region. The fall of 1926 saw him in Venezuela for the Sinclair Oil Company, and the following year he returned to the United States to accept a position as Topographic Engineer an a large detailed topographic mapping project for the city of Atlanta, Georgia.

King's initiation into aerial surveying came in 1929 when he was employed by the Aerotopograph Corporation in Washington, D. C. Short periods in 1931 and 1932 were spent with the Fairchild Aerial Surveys and the Curtiss-Wright Flying Service. This experience led to the establishment of the King Aerial Survey in 1932 in Denver, Colorado, of which he was President and General Manager.

In November, 1934, he gave up private practice to accept the position of Chief of Surveys and Maps with Region 2 of the Forest Service, located in Denver.

With the outbreak of war, the War Department assigned the Forest Service the task of constructing topographic maps of two areas in California. To accomplish this, the War Mapping Program was created with King as its Project Engineer, a position he still holds. A subsequent assignment of a new area resulted in the moving of the Program headquarters from San Francisco to Gettysburg, Pennsylvania in September of 1943. Headquarters are located in Gettysburg at present.

presupposes generous use of aerial photographs which will permit stereoscopic examination of the areas involved, these maps should certainly be made from the photos. Then, and only then, is there assurance that map and supplementary data can be brought together correctly and adequately. This, briefly, is the reason the Forest Service is interested in mapping, and suggests why this group of Forest Service engineers, though acknowledging the merits of precision equipment, found it necessary to work out a solution to their problem by less expensive means.

In general, a mapping scale of 1/31,680 (2″ to the mile) meets the majority

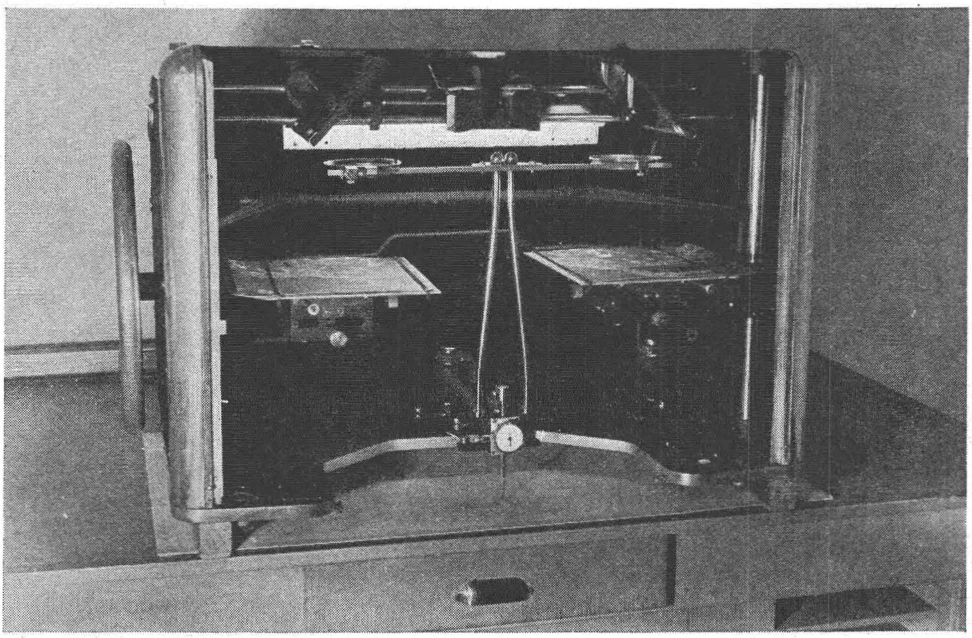


FIG. 1. Showing plotter set up for drawing with map in place.

of the Forest Service requirements. Most of the photography by the Department of Agriculture is on a 1/20,000 scale, and it was felt at the time the K.E.K. plotter was being designed that for general photo coverage of the national forests this scale was suitable and should be considered standard. The relationship between the 1/31,680 map scale and the 1/20,000 photo scale had a decided influence on the design of the first experimental models of the K.E.K. plotter.

Mapping methods prior to the designing of the K.E.K. plotter were, in general, similar to those commonly used by other agencies. Radial line picture control based on triangulation was established by the templet method, and photo details were transferred to the metal-mounted mapping sheets by vertical reflecting projector. Planimetric maps constructed by this method proved to be more accurate and less costly than comparable maps made by ground methods, but there appeared to be a possibility of further increasing the accuracy and lowering the cost if a suitable stereoscopic plotter, which would eliminate the necessity of inking culture and drainage on the photos and the need for most of the radial control points, could be found. All of the known plotting equipment on the market was studied to determine the extent to which it would meet the requirements of low cost, ruggedness of construction, simplicity of operation, and accuracy of results. It was found there was a considerable gap in stereoscopic equipment available on the market, from both cost and operational standpoints.

It was not my desire to design a piece of equipment that would replace any of the then known more expensive devices, but to fill this wide gap with a plotting machine that would:

1. Use contact prints, eliminating the costly necessity of making glass plates or diapositives.
2. Correct scale variations caused by relief.

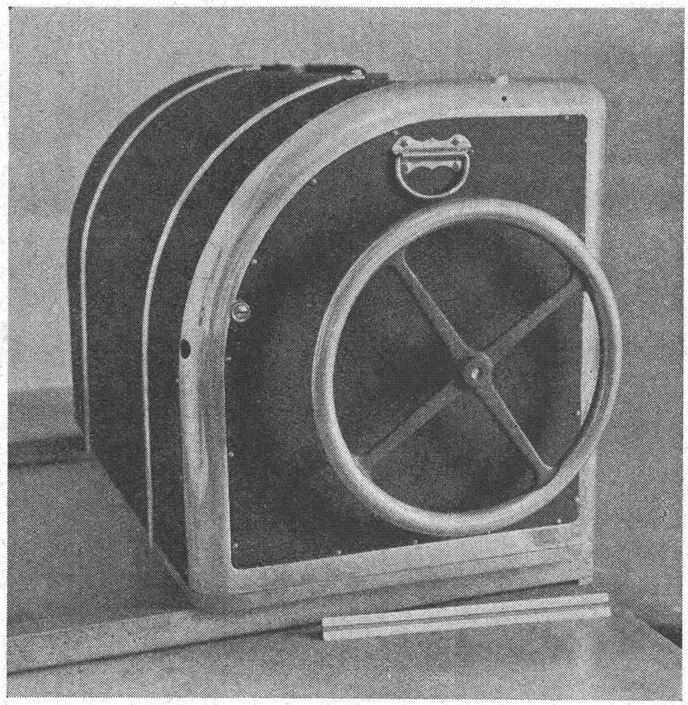


FIG. 2. Side view of plotter showing hand wheel for operating vertical movement of photo table.

3. Correct reasonable amounts of tilt, tip, swing, and camera elevations by simple means.
4. Be portable, sturdy, well-built, and accurate.
5. Have a brilliant, hard model and make the total stereoscopic model visible during operation.
6. Draw directly on the manuscript map, thus eliminating the inaccurate transfer procedure.

The K.E.K. Plotter has been designed to answer these needs and is a plotting machine which is relatively inexpensive, but capable of automatically correcting all information from the photographs, so that an accurate planimetric or topographic map can be drawn to scale in one operation. See Figures 1, 2, and 3.

The basic elements of the K.E.K. Stereoscopic Plotter are:

1. A stereoscope of the first surface mirror type, so mounted and adjusted

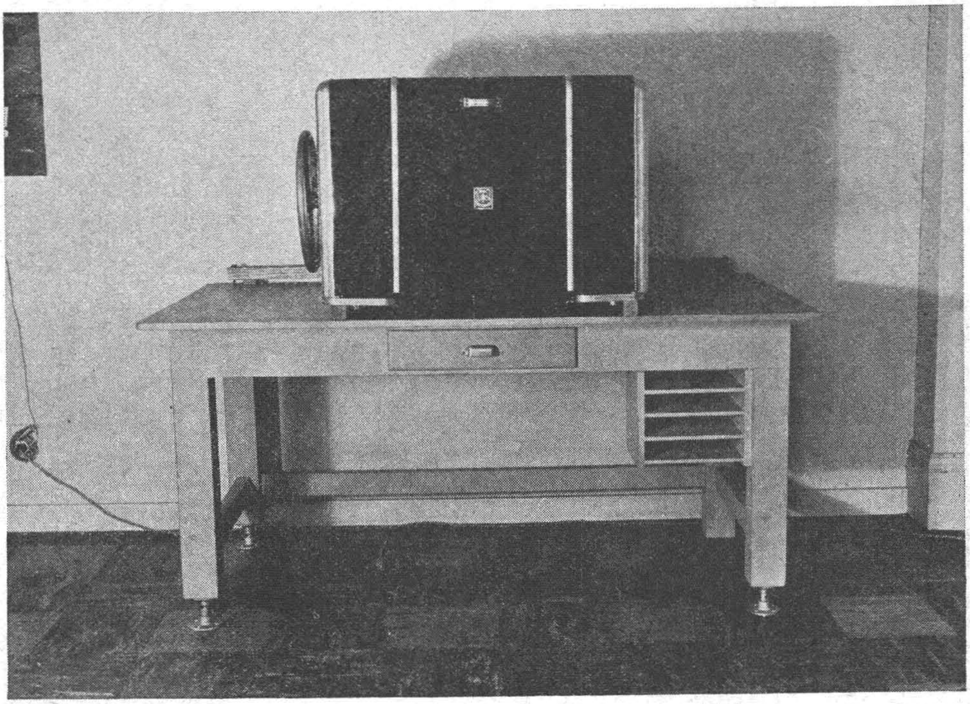


FIG. 3. View of plotting table and plotter with front cover in place.

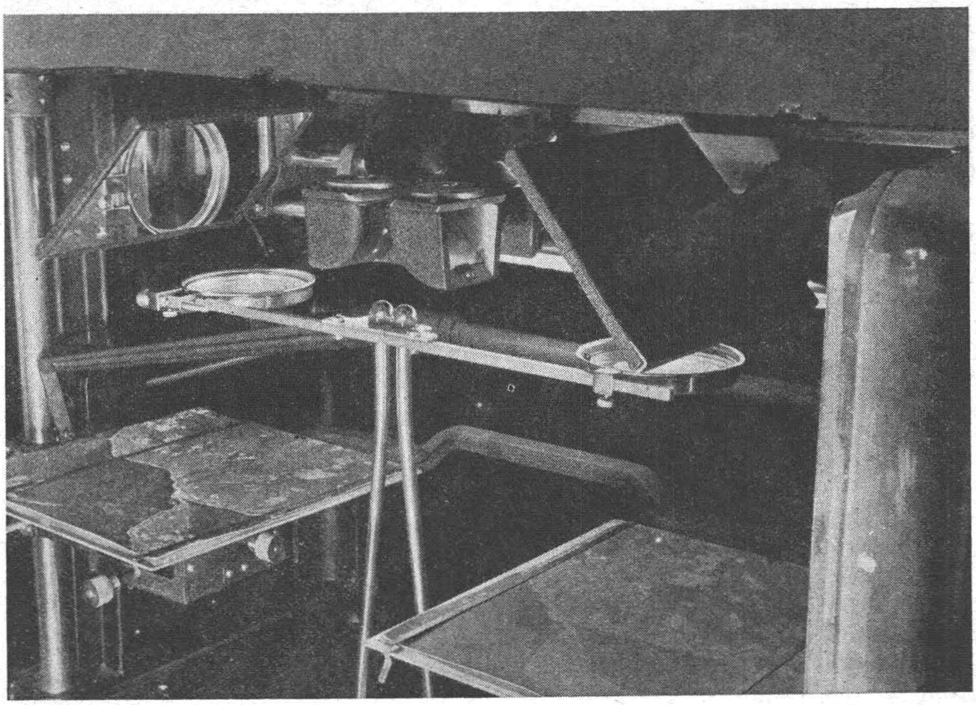


FIG. 4. Showing arrangement of optical system.

as to direct the operator's line of sight vertically over the center of each photo-table. See Figure 4.

2. A pair of photo-tables, which are movably mounted in the plotter and may be raised or lowered vertically with relation to the stereoscope by means of a hand wheel. The tables are also provided with movements for tipping, tilting, and rotating the photographs to simulate the position of the camera at the time of original exposure. See Figures 4 and 5.
3. A floating mark, consisting of a dot in the center of each of the two glass disks or lenses interposed in the line of sight between the stereoscope and the photo-tables. These disks are mounted and adjusted so as to move freely in a horizontal plane. The horizontal distance between the dots may be varied to change the scale at which the plotter draws, and they can be raised or lowered in relation to each other to accommodate the scale differences between the two prints of the model. See Figures 4, 6, and 7.

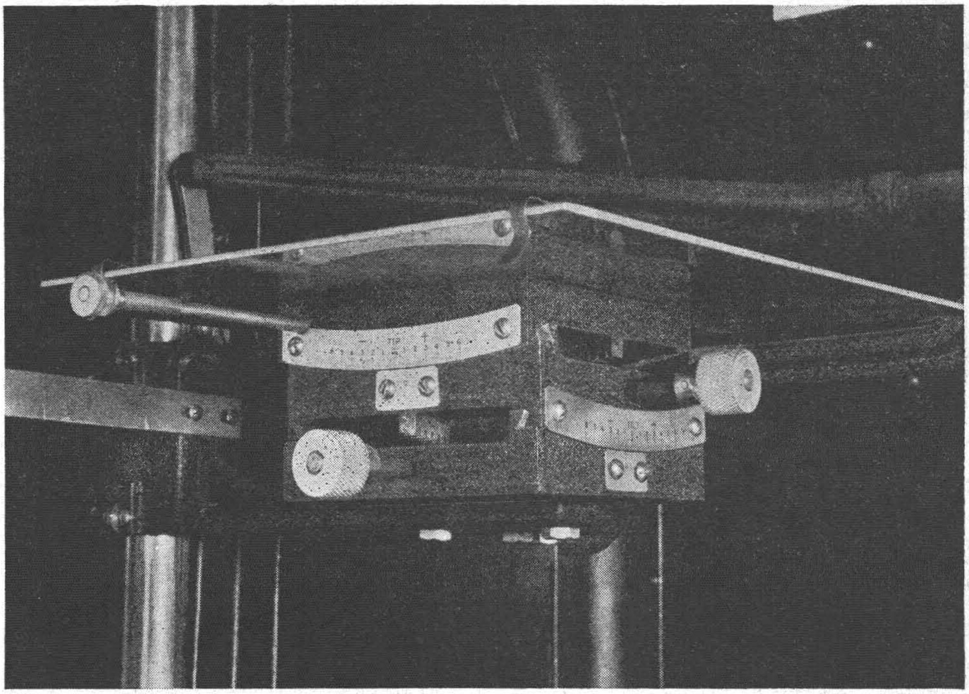


FIG. 5. Showing photo-table assembly with adjustment for tip, tilt and swing.

4. A drawing instrument which transmits the horizontal movement of the floating mark to a drawing pencil by means of a direct mechanical connection. This horizontal movement may be exaggerated or reduced by the introduction of a pantograph. See Figures 7, 8, and 9.

In actual usage the operator views an apparent three-dimensional model. He simultaneously sees the floating mark, which remains at a fixed distance from his eye. Hence, it is obvious that the model must be raised or lowered to bring the floating mark into contact with points of different elevation.

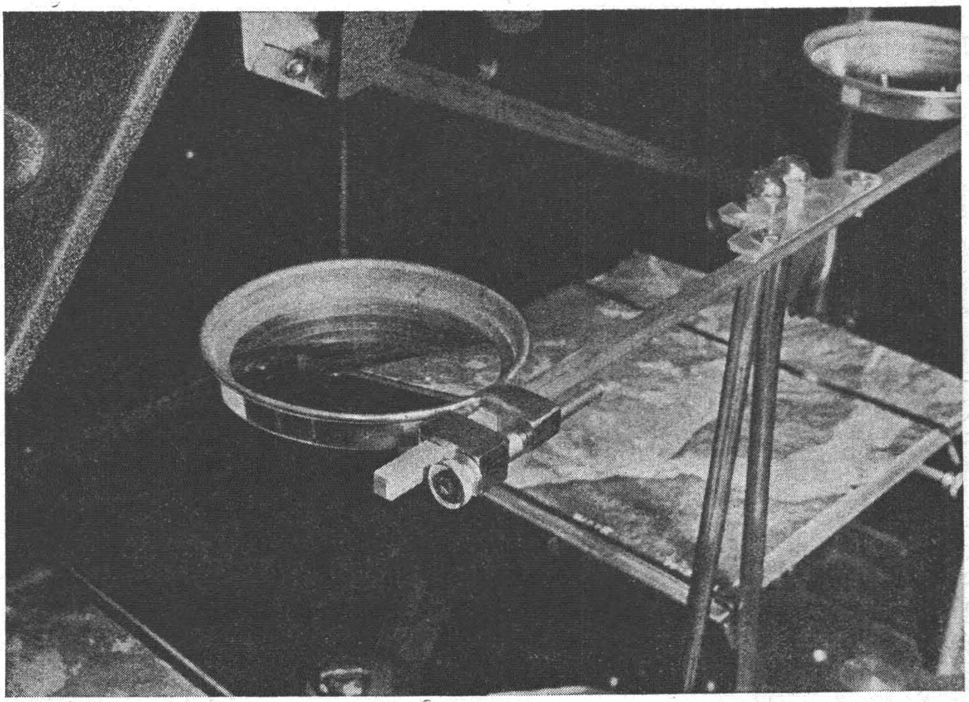


FIG. 6. Showing one of the floating dot lenses with screw adjustment for changing the plotting scale.

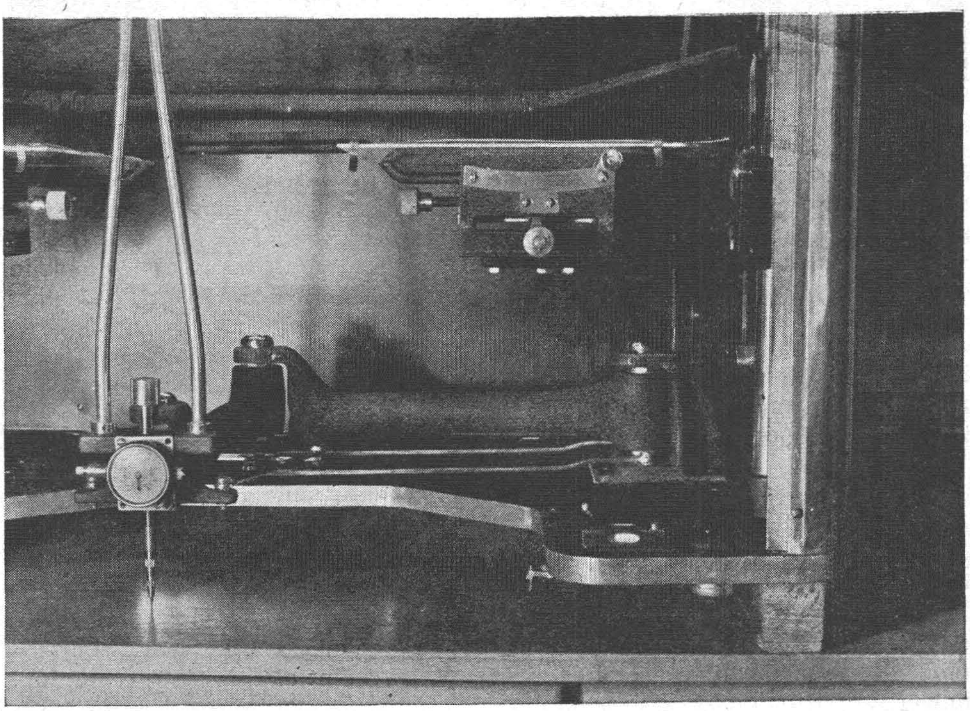


FIG. 7. Showing drawing arm which keeps the floating dot parallel and moving on the horizontal plane. The dial gauge is for testing the accuracy of the arm.

In delineating the planimetry of any feature of varying elevations the model is constantly raised or lowered so that the floating mark will appear to maintain contact with the surface of the feature being drawn. In tracing contours the model remains stationary at a predetermined elevation, and the floating mark will contact the surface only at points of equal elevation.

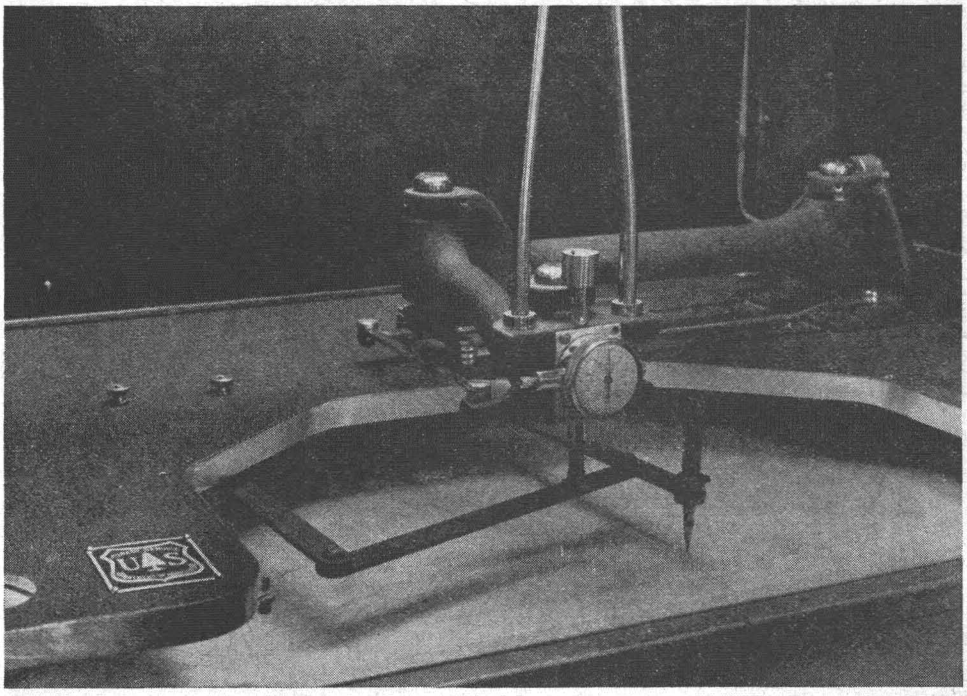


FIG. 8. Showing pantograph attachment to the drawing arm.

The most distinctive feature of the K.E.K. plotter is the measurement of parallax due to differences in elevation by a vertical movement of the stereoscopic model rather than the floating mark, which moves in a horizontal plane only. This makes possible a complete view of the model at all times and, in conjunction with the pantograph attachment, a better control over the viewing distance and a large construction scale range. For example, from a contact print scale of 1/20,000 the plotter can be adjusted to draw to any scale from 1/20,000 to 1/31,680 simply by varying the horizontal distance between the dots of the floating mark. With the pantograph a drawing scale of from 1/15,000 to 1/45,000 is possible, using the 1/20,000 contact prints. With the photographs and construction scales ordinarily encountered, the model can be drawn in the upper range of its vertical motion by selecting the proper combination of pantograph ratio and horizontal spacing of the floating mark dots. This has the advantage of keeping the model near the operator's eye, where maximum plotting accuracy is possible.

The amount of vertical motion required to conform to a given difference of elevation is a function of a number of factors, one of which is the viewing distance of the model. Because of the vertical movement of the photo-tables and model the latter factor is a variable, and the apparent vertical elongation of the model has a direct relationship to it. This variable vertical scale has been

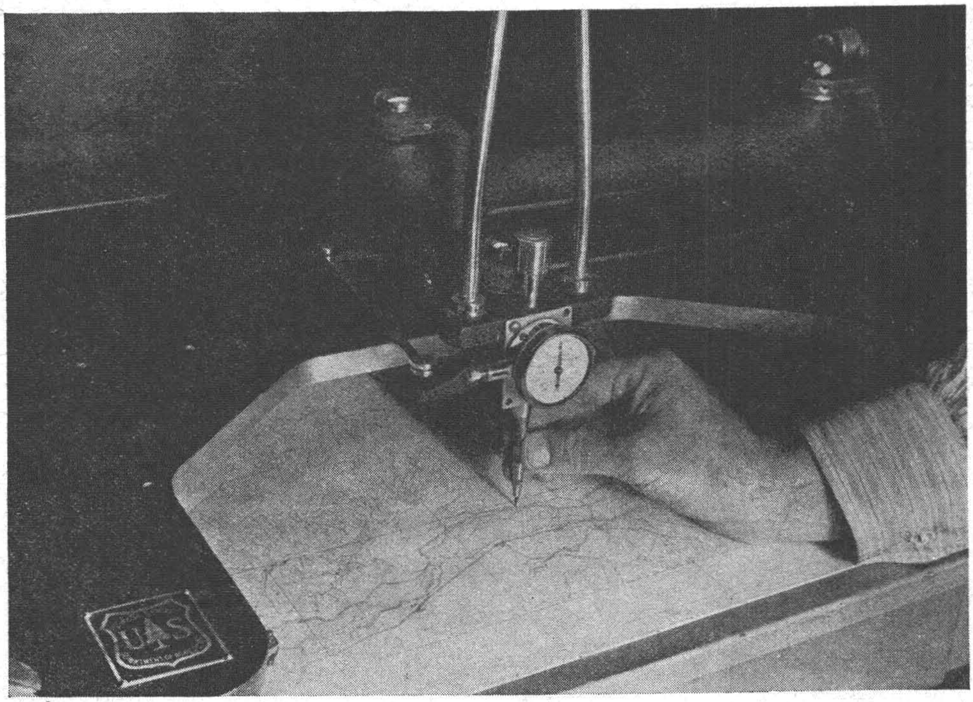


FIG. 9. Showing plotting pencil and method of drawing directly on to the map sheet.

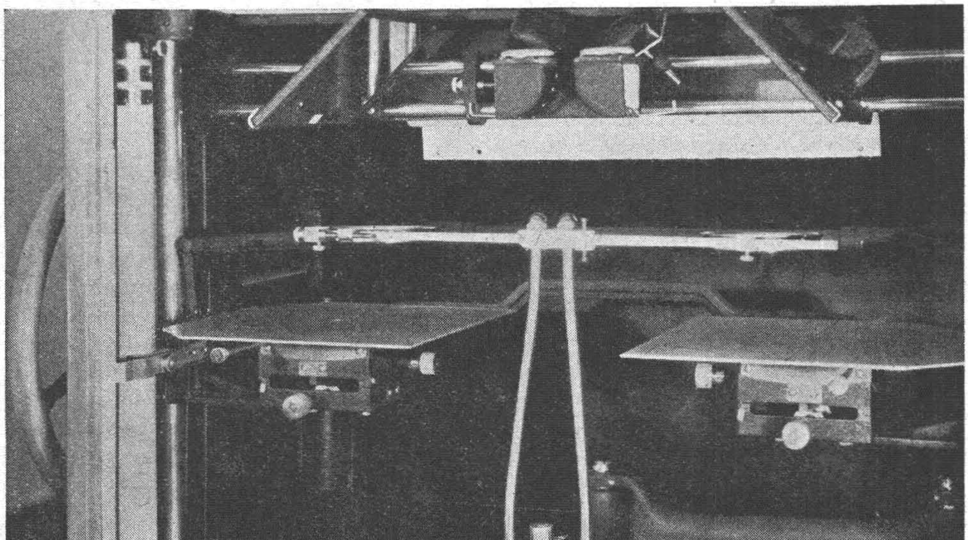


FIG. 10. View of vertical scale in relation to the photo tables.

computed and plotted as the hyperbolic equation $X=C/Y$, in which X is the viewing distance in the plotter, Y is the viewing distance of the camera, and C a constant which is the product of the focal length of the camera, the construction scale of the map, and the distance from the eye to the floating dot.

For compactness and simplicity the plotted vertical scale is mounted on a cylinder fixed on the inside of the plotter. (See Figure 10.) A transparent sleeve

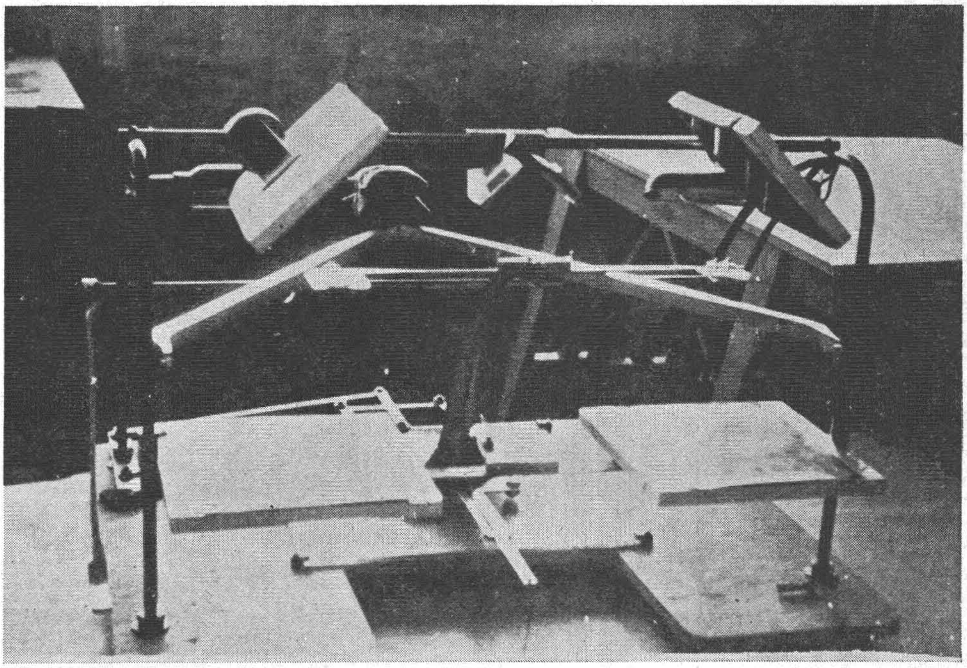
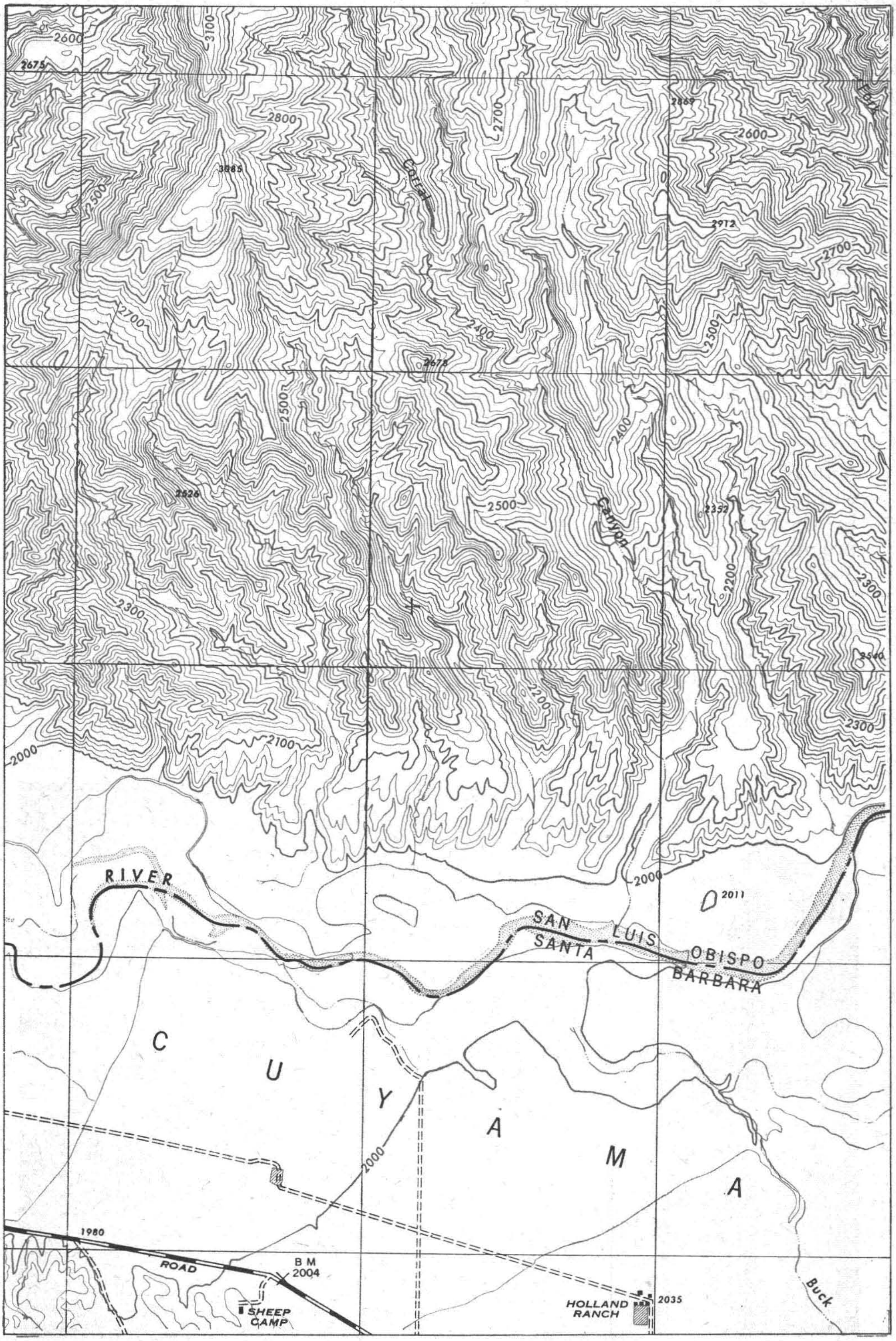


FIG. 11. First model.

bearing inscribed cross hairs is fitted around the cylindrical scale to act as an indicator. The common construction scales are represented by vertical lines cutting across the plotted hyperbolic curves. If the pantograph attachment is not being used, the proper vertical scale is established by revolving the cylinder until the vertical hair of the indicator sleeve is superimposed on the line marking the scale to be used. Correction factors for all pantograph ratios have been provided, and may be set off directly from the construction scale line. A final minor adjustment to make the scale readings agree with actual control elevations is accomplished by moving the entire cylinder up or down a short distance.

The K.E.K. plotter is dependent on control on individual stereoscopic models. Assembly of these in correct position and orientation is usually provided by radial line methods. However, the original manuscript map is oriented underneath the plotting machine, enabling the operator to draw directly without any transfer procedures. (See Figures 8 and 9.) The first working model of this plotter was made in the Forest Service office, Denver, Colorado, in 1938 (see Figure 11) with the idea of utilizing this machine for planimetric mapping only. However, the first test from this crude model showed beyond a doubt that with some changes in the design and construction we had the machine we were looking for—an instrument that would facilitate the needs of both a map maker and map user and would utilize a vast majority of the material on hand.



Scale 1: 20,000 Contour interval = 25 feet

FIGURE 12

The Forest Service immediately went to work to construct two of these machines in their improvised shop. This procedure proved to be long and laborious, with no funds available for such work. Consequently, a great amount of the time spent in the construction of these two machines, as well as the experimental model, was donated in the form of overtime by those who believed the machine would work and had confidence in its wide applicability to Forest Service mapping problems. These two machines were completed early in 1941 and were patented November 25 of that year as J. E. King, J. W. Elliott, and P. B. Kail, assignors to Claude W. Wickard as Secretary of Agriculture of the United States of America and his successors in office, under Patent No. 2,263,971.

The plotter has been inspected by a number of photogrammetric authorities, all of whom have commented favorably on its potentialities. Some aspects of its design and operation, however, have received criticism. The most important is concerned with the putative violation of certain principles of photogrammetry in connection with the moving model. The inability to bridge horizontal control and the apparent need for a great amount of vertical control have also been pointed out as serious defects. However, the proof of the pudding is in the eating. At the outbreak of World War No. 2 the Forest Service was called upon by the War Department to embark on an emergency topographic mapping program. From March 1942, when the first parties went into the field, to June 30, 1944, the Forest Service completed with twenty K.E.K. plotting machines three assignments. One, comprising fifty 7½-minute quadrangles, located in southern California, was worked on a manuscript scale of 1/15,840 with a contour interval of 25 and 50 feet. A second project of nine 15-minute quadrangles in northern California was mapped on a 1/31,680 scale with a 50 foot contour interval. The third assignment consisted of forty-six 7½-minute quadrangles in Pennsylvania, Maryland, Virginia, and West Virginia, and was worked on

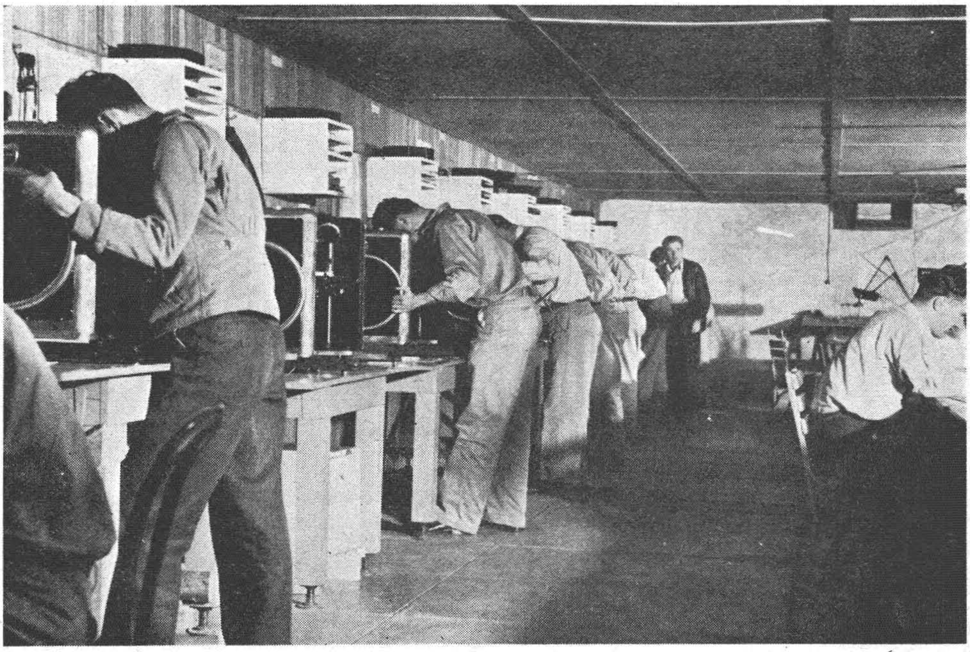


FIG. 13. Field plotting room in operation.

a manuscript scale of 1/15,840 with a 20 foot contour interval. The areas covered by these assignments included a wide variety of topographic types, ranging from gentle rolling and naturally eroded areas in Pennsylvania and Maryland to the extremely rugged and badly faulted Coast Ranges of southern California. Figure 12 is an actual reproduction of a portion of one of the 7½-minute quadrangles mapped in southern California. This example can be regarded as typical of K.E.K. topography. The total area included 7024 square miles, mapped to the following specifications:

Horizontal—All easily identifiable and recoverable points depicted will appear within .02 inches of their true geographic positions, and 90% of all features will appear within .04 inches of their true geographic positions. No point will be more than .075 inches from its true geographic position.

Vertical—90% of all contour lines will show true elevations of the ground surface, as referred to the 1929 adjusted level net, North American Datum, within half a contour interval, and no contour elevations will be in error by more than a full contour interval.

To insure the attainment of the required accuracy, the Forest Service ran 56 miles of profile line to third-order accuracy, established independent positions for 1756 identifiable points by triangulation, plane table, or radial line intersection methods, and located 5506 independent elevations. This extensive checking was distributed evenly over the 105 completed quadrangles. In addition to this instrumental check, each and every quadrangle was inspected in the field by a competent topographic engineer, resulting in the rejection of one entire quadrangle and small portions of two others.

During this operation, the K.E.K. plotter was subjected to practically every type of working condition known, from well equipped central offices to isolated pack camps where gas lanterns and batteries were used for illumination. (See Figure 13.) Differences in output resulting from these widely varying conditions were found to be due entirely to human, rather than instrumental, factors.

However, past experiences show that further simplification of horizontal and vertical control procedures can be obtained by the use of terrestrial photogrammetry. I might say that the Forest Service is now conducting an extensive experiment along these lines, which no doubt will be covered by another article. Also the possibilities of the use of analytical methods of extending supplementary control should not be overlooked.

It is my belief that the progress of photogrammetry has been greatly retarded by not having a more simple and economical plotter for obtaining the required results. Whether or not the K.E.K. plotter fills this gap, some instrument of this nature must be devised before full advantage can be taken of the science of photogrammetry.