

Oct. 16, 1945.

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2,386,816

STEREOSCOPIC MODELING MACHINE

Filed Aug. 11, 1944

4 Sheets-Sheet 1

FIG. 1

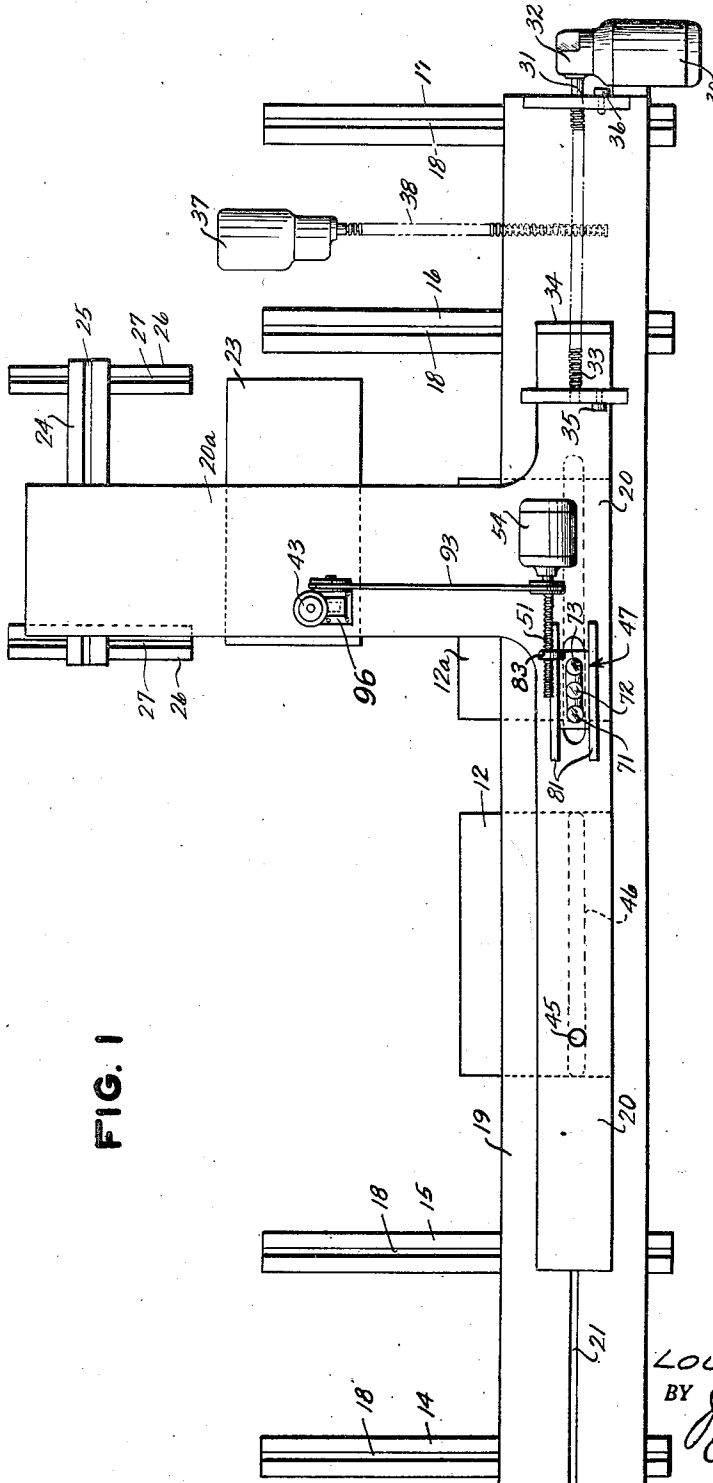
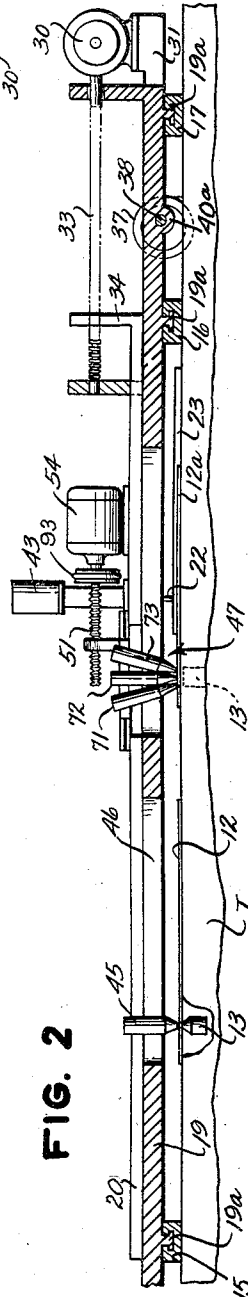


FIG. 2



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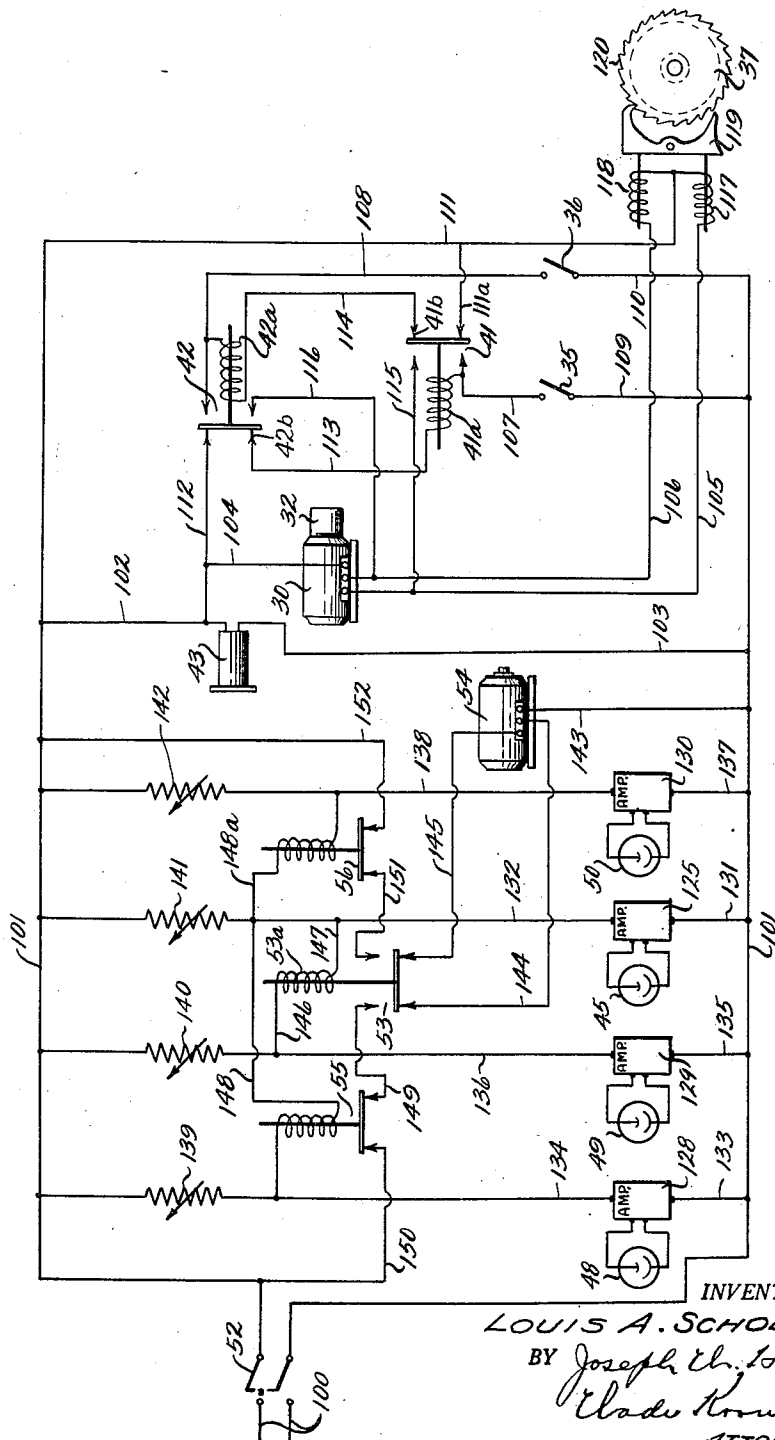
2,386,816

STEREOSCOPIC MODELING MACHINE

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File 3



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FIG. 4

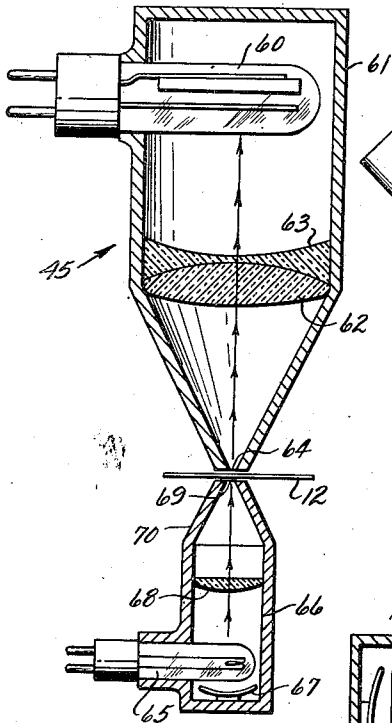


FIG. 5

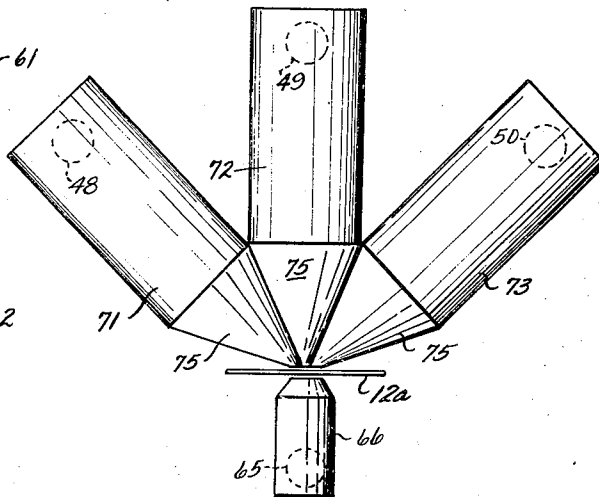


FIG. 6

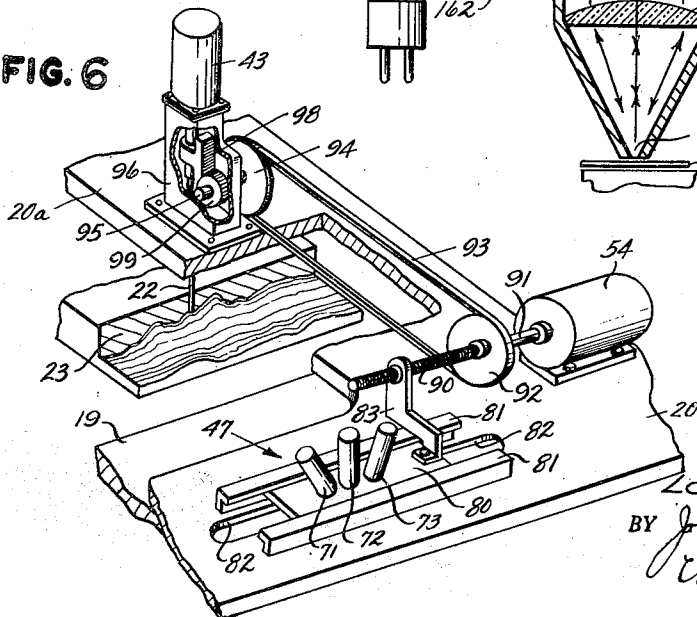
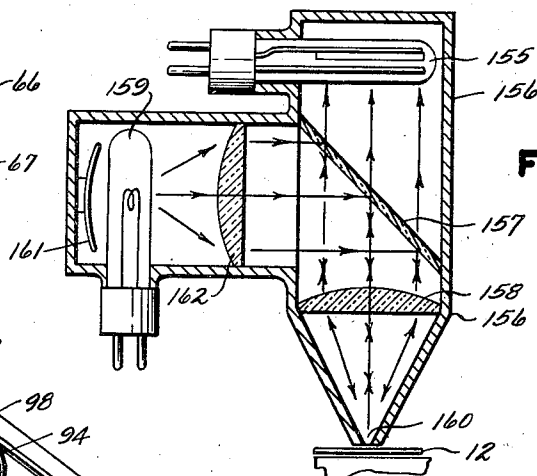


FIG. 7



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STEREOSCOPIC MODELING MACHINE

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FIG. 9

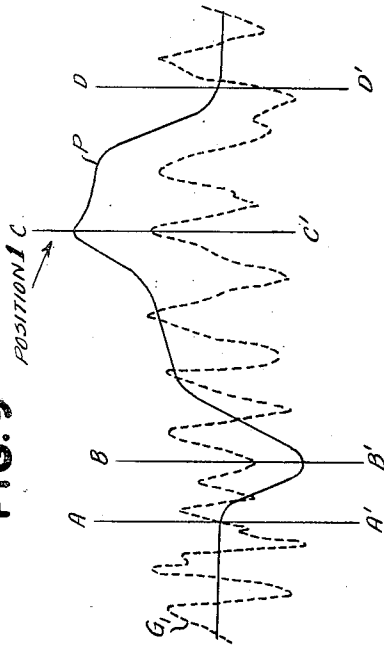


FIG. 8

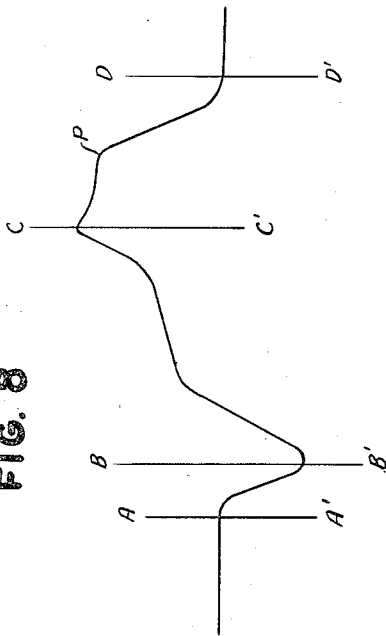


FIG. 11

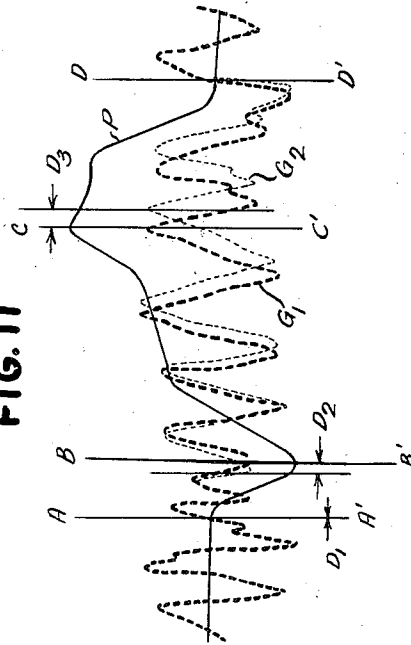
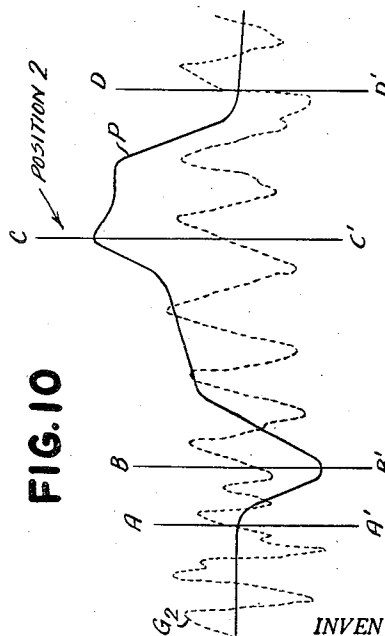


FIG. 10



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UNITED STATES PATENT OFFICE

2,386,816

STEREOSCOPIC MODELING MACHINE

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Application August 11, 1944, Serial No. 549,106

7 Claims. (Cl. 90—13.8)

(Granted under the act of March 3, 1883, as amended April 30, 1928; 370 O. G. 757)

The invention described herein may be manufactured and used by or for the Government for governmental purposes, without the payment to me of any royalty thereon.

This invention relates to stereoscopic modeling machines, and, in general, aims to provide a practicable method and means for automatically and accurately reproducing on any desired scale, either in relief or in intaglio, the physical features of a part of the earth's surface (or other photographed object) by electronic scanning of a pair of stereoscopic photographs of the object. By the preferred method, photoelectric cells are used to record variations of intensity of light from corresponding points on two stereoscopic photographs, and a cutting tool is moved over a plastic or other surface to be carved, to reproduce automatically a replica or counterpart in three dimensions of the photographed object. As the apparatus is wholly automatic, it imposes no eyestrain upon the attendant or operator, and does not require a high degree of skill. The personal equation is completely eliminated, once the apparatus has been adjusted to the stereo pair it is to reproduce. The invention may be useful in relief map making, in sign-making, or in the fine arts, or wherever reproductions in relief or in intaglio are desired. As the invention depends on photoelectric cells (or their equivalent) which are so sensitive that they will pick up a dot as small as the circle of confusion of the most accurate lens, the apparatus may be many times more sensitive and accurate than the human eye. Other objects and advantages will be apparent from the following description.

The prior art contains several references to apparatus for reproducing portraits, etc., in relief from stereoscopic photographs. The earliest known Patent No. 1,090,493 to Von Orel dated March 17, 1914, discloses a carving tool guided by the hands of the operator while he looks through a monocular or binocular microscope at a pair of stereoscopic photographs. According to the Townsend Patent No. 1,486,814 dated March 11, 1924, a grooving tool is moved horizontally and vertically over material to be cut in relief or in intaglio, to reproduce in three dimensions the object of a pair of stereo photographs. Movement is effected by manual turning of three lead screws each controlling travel of the tool in one of three planes. By employing a pair of index fingers or pointers, the variations between the two stereo photographs may be measured, and the variation or displacement between any two like points on the stereos caused the cutting tool

to cut vertically more or less deeply, proportionately to said displacement. James Dorn in Patent No. 2,047,013, dated July 7, 1936, shows schematically an arrangement for reproducing objects by passing light through the walls of a three dimensional model onto a light-sensitive device, the model being given synchronous axial and rotational movements so that the light is transmitted through every part of its walls. The light-sensitive device is hooked up with a cutting tool and the work is moved synchronously with the model and is shaped by the cutting tool to the same form as the model. The action depends on the transmission of light through varying thicknesses of the walls of the model and no stereoscopic photographs are employed. In Patent No. 2,283,226 dated May 19, 1942, H. B. Porter discloses a method and means for contouring aerial maps by scanning automatically stereoscopic photographs, but reproduction of the image or stereo pair is not contemplated. My invention has important advantages over all these disclosures, since it provides for the first time a purely automatic and highly sensitive and accurate machine for carving a three-dimensional image, in relief or in intaglio and on any desired scale, of an object photographed stereoscopically.

In the accompanying drawings showing diagrammatically the preferred form of apparatus for practicing the invention:

Fig. 1 is a plan view, omitting the electric wiring and other control details;

Fig. 2 is a side elevation partly in section;

Fig. 3 is a schematic wiring diagram;

Fig. 4 is a diagram in section, on a large scale, of a single photocell unit adapted for transmission;

Fig. 5 is an elevation of the three cell unit;

Fig. 6 is a perspective schematic view of the control of vertical movement of the cutting tool;

Fig. 7 is a diagram in section, on the scale of Fig. 4, of a single photocell unit adapted for reflection;

Figs. 8 to 11 inclusive are graphs to aid in explaining the theory of the apparatus.

Before describing the preferred apparatus, reference should be made to Figs. 8 to 11 inclusive. Fig. 8 shows a profile P of a hilly or mountainous area, the vertical scale being much larger than the horizontal scale. Figs. 9 and 10 show light intensity graphs G1 and G2 respectively, obtained by photometric methods, the area of Fig. 8 being comprehended within each graph, which is shown with profile P. The ordinates represent light intensities of the points of the earth's sur-

face along profile P, as viewed from the two camera positions indicated by the legends and arrows. It will be understood that due to the limitations of the drawing sheet, the actual elevation of the camera relative to the ground is not shown in Figs. 9 and 10. These intensity graphs are superficially identical, but when superimposed, as in Fig. 11, differences are readily apparent. These differences are due to the foreshortening effect of the change of the camera position from position 1 to position 2, corresponding points of equal photographic density or intensity being given a horizontal displacement proportional to D_1 , D_2 , D_3 , etc. As shown, the graphs G_1 , G_2 coincide as far as line A—A', indicating that there is no change in elevation in that portion of profile P, or D_1 equals zero. From line A—A' to line B—B', the original profile descends; thus the intensity graph G_1 leads the intensity graph G_2 until these graphs are apart a distance equal to D_2 . From line B—B' to line C—C' the original profile ascends, and the intensity graph G_1 lags behind graph G_2 until these graphs are spaced apart in the opposite direction a distance equal to D_3 . From C—C' to line D—D', profile P descends, and again graph G_1 leads graph G_2 until the graphs are coincident, at line D—D', showing that the original profile has returned to the starting level or datum plane. Now an automatic stereoscopic modeling machine need only compare the densities of the same point photographed on two stereo negatives (or positives) and then need only record the horizontal displacement of the two images of said point as vertical or altitude differences, on some material capable of taking and preserving the impressions in permanent form. This result is accomplished by the apparatus described herein.

The preferred apparatus is adapted to be supported on a flat table top T (Fig. 2) on which a pair of stereoscopic photographs 12, 12a of the same object are laid flat. Some arrangement may be made for supporting the photographs so that their relative positions may be slightly altered, as for instance by means of a pair of fine-threaded manually operated screws acting on a frame holding one of the photographs and adapted to move the frame parallel to the table top in either of two directions at right angles (not shown). Preferably the photographs are negatives, and a source or sources of light, preferably two electric lamps 13 (white or colored as desired) are located beneath the table, one lamp being below each negative, with a switch to control both lamps, as will be understood without illustration. Thus light rays pass through both negatives and may be picked up at any point above either negative to activate light-sensitive cells to be described. The proper adjustment of the relative position of the negatives may therefore be determined optically by inspection of the negative against a horizontal grid (not shown) held above the table top prior to operating the apparatus.

Secured to the table top are four parallel guiding blocks 14, 15, 16, 17, each having a straight T-shaped slide or slot 18 cut in its upper face. An elongated flat guide rest 19 has its underside provided with tongues 19a to fit in the slots 18; thus the guide rest 19 is spaced above the table top and may reciprocate parallel thereto directly above the photographs. For convenience, the direction of this reciprocation is herein termed "lateral," while the direction at right angles thereto is termed "longitudinal." Slidably mounted on top of the guide rest 19 is a tool sup-

port 20 having an arm 20a extending at right angles, a straight V-shaped slide 21 being provided on the upper surface of guide rest 19 for guiding relative sliding of the tool support. A vertical rotary cutting tool 22, driven and controlled as will be described later on, is carried by arm 20a and extends down into contact with or proximity to a reproductive bed 23 which may be of many different materials such as wood, plaster of Paris, wax compound, chalk, graphite or talc compound, a plastic, or other readily carved material having the necessary texture or "reproductive sensitivity" to reproduce small surfaces and lines. The bed 23 is shown as supported on the table top, and as it is to be carved, it must be clamped thereon (not shown). The outer end of arm 20a may be slidably supported on a guiding block 24 having a V-shaped groove 25 parallel to slide 21. Another pair of parallel guiding blocks 26 are shown, each being fixed to the table top and having a V-shaped groove 27 parallel to slides 18, said guiding blocks 26 supporting and guiding block 24 when tool support 20 is moved laterally by sliding of guide rest 19 over slides 14—17. The under side of block 24 will have V-shaped projections fitting in grooves 27, as will be understood. By the described arrangement, the cutting tool 22 is movable over the reproductive bed in either of two directions at right angles to each other, in a plane parallel to the table top. As the reproductive bed has its upper surface initially plane and parallel to the table top, such surface will be inscribed or carved when the cutting tool is properly actuated in vertical planes.

To move the tool support 20 along the guide rest 19, a small 3-terminal constant speed reversing motor 30 is employed, and for convenience it is mounted on the guide rest, preferably on flange 31 which projects at right angles from one end of the guide rest. Motor 30 preferably is of the type which houses in its casing a solenoid braking clutch 32 (Fig. 3) to cause it to stop quickly when de-energized, and preferably has a reduction gear train (not shown) also built inside the casing. Similar motors are used to control various devices in aircraft, hence the motor is not described in detail. The gear train directly drives a lead screw 33 whose thread may be very fine; that is, having a pitch of one one-hundredth of an inch, more or less. Similar lead screws are in use in sound recording and reproducing machines. Meshing with the threads of lead screw 33 is a nut 34 fixed to tool support 20. Thus nut 34 is moved back and forth to cause reciprocation of the tool support. Reversal of motor 30 is obtained through limit switches 35, 36, which may be directly contacted by the traveling nut as it reaches either limit of movement. The speed of motor 30 and the reduction through the described gearing may cause the traveling nut to move from one extreme position to the other during one to five minutes, more or less, depending on the size of the stereoscopic photographs on the table and on the size of the reproductive bed, which it should be clear, may be many times larger than the photographs, although for convenience of illustration being shown as of the same size.

Movement along slides 14, 15, 16, 17 and 26 is controlled by a motor 37, driving a fine-threaded lead screw 38 (similar to lead screw 33) which is supported on bearings (not shown) fixed to the table top. Screw 38 engages a threaded boss 40a (Fig. 2) on the guide rest 19. Motor 37 is operated through relays 41, 42 (Fig. 3) each time

the traveling nut 34 contacts one of the limit switches 35, 36, thereby to move the entire assembly supported on slides 14—17 through a small increment, which may be one two-hundredth of an inch. Thus the cutting tool 22 is moved along the entire length of the reproductive bed, then is advanced laterally through the desired increment and moved in the opposite direction along a path parallel to the path first traversed, then is advanced laterally through the same increment and moved along a third path parallel to the other two, and so on until the machine is stopped by the operator, or automatically if preferred. The cutting tool may be similar to a dental type drill, and necessarily is of small diameter.

To drive the cutting tool continuously while the apparatus is operating, a motor 43 of perhaps one one-hundredth horsepower is employed and is supported on arm 20a by means not shown, with the cutting tool directed downwardly. If desired, a small fan (not shown) also driven by motor 43 may blow the fine particles or grains dislodged by the cutting tool, so that there is no tendency for these loose particles to collect in depressions cut in the reproductive bed, which might cause some uncontrolled abrasion of the three-dimensional image being formed, with resultant distortion or blurring some of the surfaces of said image. Furthermore, a fan is desirable to prevent particles of a dust-like nature from settling on the negatives during operation of the machine. For this purpose an additional fan adjacent the negatives may be employed, or one large fan may be located directly over the apparatus to continually blow away all atmospheric dust as well as particles rising from the carving operation. Either arrangement will be understood without illustration. Instead of a fan or fans, a suction head (connecting with a vacuum line) may be located adjacent the cutting tool (not shown) to pick up particles from the surface of the reproductive bed during the carving.

The operation of any stereoscopic device depends on the foreshortening of any object proportionally to its height above the datum or base plane, which foreshortening takes place along the axis of separation; that is, the axis or straight line between common points of the stereo pair. The present machine is so designed that it picks up density values of two corresponding points of the stereo pair, and compares these values and records (on the reproductive bed) a vertical cut equal to or proportionate to the horizontal displacement along said axis.

To pick up and compare the density values of corresponding points of the stereo pair, I employ a unique arrangement of photocells and cooperating parts with one photocell unit 45 preferably fixed to the tool support 20 to participate in the longitudinal and lateral movements thereof (relative to photograph 12). To permit photocell unit 45 to be exposed to the light densities of every point of photograph 12, the guide rest is slotted, as best shown at 46, Fig. 2, so that no part of the guide rest is interposed between the photograph to be scanned and the scanning element 45. Obviously if the stereo photographs are located above the machine, as is entirely feasible, it is unnecessary to provide a slot 46, but the scanning element must then be reversed to pick up light densities from the photograph. Cooperating with unit 45 is a 3-cell analyzer unit 47 comprising photocells 48, 49, 50, which must be so located on the tool rest as to pick up light densities of three adjacent points of photograph 12a along a line par-

allel to the path of movement of the tool support 20 on guide rest 19. Before explaining how three adjacent points of photograph 12a are picked up by the 3-cell unit, the interaction of the two units should be outlined.

Let us suppose that photocell unit 45 is at the lower right hand corner of photograph 12, which may be considered as the starting point of the scanning operation, then the 3-cell analyzer unit 47 is moved by a screw 51 until the middle cell 49 is receiving light from the corresponding point on photograph 12a. Then operation is started by closing a main switch 52 (Fig. 3) energizing motor 30 to cause travel of the tool rest to the left (as viewed in Fig. 1). If while this travel occurs the intensity of a pin point of light reaching photocell unit 45 exactly equals the intensity of light striking photocell 49, there is an electrical balance in a circuit including relay 53, which opens to de-energize motor 54, which may be a "Selsyn" unit, that is, a self-synchronous unit so built that when it is coupled electrically to a similar unit, it will duplicate any turning movement thereof. It is not essential that a "Selsyn" unit be used as other reversible and quickly stopped motors could be employed. This action will be understood by studying Fig. 3. However, should the profile of the photographed object be rising or falling, the light intensities reaching photocells 45 and 49 will be unequal. If the profile is rising, photocells 45 and 50 balance each other while photocells 48 and 49 do not. This condition energizes relays 53 and 55 and leaves relay 56 de-energized, thus starting motor 54 to drive the 3-cell unit 47 to the right as viewed in Fig. 1, until the middle photocell 49 is in the balancing position, when the circuit of motor 54 is opened. On the other hand, should the profile be falling, cells 45 and 49 will be unbalanced and 45 and 50 will also be unbalanced, while cells 45 and 48 will be balanced, thus leaving relay 55 de-energized and relays 53 and 56 energized, which will start motor 54 to move the 3-cell unit to the left. Cell 49 always tends to be centered over the density point of photograph 12a that exactly equals the corresponding point of photograph 12. It will be clear that the 3-cell unit 47 analyzes automatically the direction in which the cutting tool should be moved to cut a profile like that of the object photographed. The 3-cell unit may therefore be considered as the "brain" of the machine, while the cutting tool is like a hand directed by the "brain."

Now referring to Fig. 4, which is a diagram of photocell unit 45, a photocell 60 is mounted in one end of a sealed casing 61 which excludes all light from the cathode except the rays admitted through an achromatic lens system, here shown as a convex lens 62 and concave lens 63. The lens system is housed in casing 61, which tapers to a point where there is a tiny light aperture 64. This aperture is above the negative 12 through which light passes, from a light source shown as an electric lamp 65 carried in a housing 66 having a reflector 67 and a converging lens 68 to focus the light rays to a point at the aperture 69 of the tapered end 70 of housing 66. With this arrangement, housing 66 must be supported on the underside of the negative 12 and must travel synchronously with the photocell unit 45 and to the same extent. There are various mechanical methods of accomplishing this result, none of which is shown.

In Fig. 5 there is shown an arrangement for picking up light from three adjacent points in straight line succession and then transmitting the

light to three photocells 48, 49, and 50 which are located in light-excluding housings 71, 72, and 73, respectively, each housing having a lens (not shown) adjacent the tapered end 75 thereof, the arrangement being similar to that of Fig. 4. The three tapered ends of the housings are juxtaposed, and each has an aperture (not shown, but similar to aperture 64), about .02" in diameter and so located that it is directly above the light source. Light passing through negative 12a reaches the pointed tips of housings 71, 72, 73 and is transmitted by said apertures to the lenses (each of which may be replaced by a lens system as in Fig. 4) and through the lenses to the sensitive cells 48, 49, 50.

A diagrammatic illustration of means for translating the variation or displacement between any two like points on the stereo pair into vertical movements of the cutting tool is shown in Fig. 6. Here the three-cell unit 47 is shown as secured to a slide 80 supported on tool support 20 and guided by parallel angles or other guides 81.

An elongated slot 82 in the tool support permits light rays to reach the three-cell unit 47. An arm 83 is fixed to slide 80 and has a threaded opening for receiving a worm 90 which is on the end of shaft 91 driven by "Selsyn" type motor 54 also carried on the tool support. If desired, the worm 90 may be driven through reduction gearing (not shown) and it may have very fine teeth to give close control of the position of three-cell unit 47, while the "Selsyn" motor 54 may have several windings to permit increments of movement of as little as one-third of a revolution or less. A pulley 92 (or a sprocket wheel) is fixed to shaft 91 and a belt 93 (or a sprocket chain) is trained about part 92 and also about a pulley or sprocket 94 on a shaft 95 supported on motor head 96 on which the carving motor 43 is mounted. Guides are indicated to permit the motor head and motor to move vertically or at right angles to the top (outer surface) of the reproductive bed 23. A vertical rack 98 on the motor head is reciprocated by a pinion 99 fixed to shaft 95. It will be clear that each time "Selsyn" motor 54 is energized, the three-cell unit 47 will be moved in one direction or the other, the total movement permitted being, however, not over 15% of the length of the photographs 12, 12a. Simultaneously, the motor head and the rotating cutting tool 22 will be moved up or down. Obviously, the reduction gear between motor 54 and shaft 91 and slide 80 may have almost any ratio and hence, the vertical movement of the cutting tool may be magnified or decreased in accordance with the desired results on the reproductive bed.

Now referring to Fig. 3, a source of electricity 100 is connected through main switch 52 with leads 101, to which the cutting motor 43 is coupled in series by conductors 102, 103. The longitudinal scanning motor 30 is joined by conductors 104 and 102 to one of the leads 101 and is coupled through conductors 105, 106 to motor 37, which effects lateral motion of the tool rest 20 during scanning, as described above. A double pole, double throw, normally open relay 41 is connected to limit switch 35 through conductor 107 while a similar relay 42 is connected to limit switch 36 by conductor 108. The two limit switches 35, 36 are coupled to one of the leads 101 by wires 109, 110 respectively. A conductor 111 joins relay 41 with the other lead 101 and a corresponding conductor 112 couples relay 42 with the same lead 101. Relays 41, 42 are electrically interlocked,

as shown, a conductor 113 joining the solenoid 41a of relay 41 with a terminal 42b of relay 42, and a conductor 114 joining solenoid 42a with terminal 41b of relay 41. The two relay circuits are completed through wires 115, 116, which couple the relays to conductors 105, 106 respectively, and through a lead 111a which connects relay 41 to conductor 111. Now motor 37 is energized through conductors 105, 106, which respectively energize solenoids 117, 118 which in turn move a double-ended pawl 119 over ratchet 120 to permit a very small increment of lateral movement of the guide rest 19. It is clear that motor 30 is always driven in one direction or the other, depending on which relay 41, 42 is closed, and that motor 37 is energized only momentarily, at each reversal of motor 30.

Continuing the description of Fig. 3, each of the photocells 45, 48, 49 and 50 is coupled in parallel with an amplifier 125, 128, 129 and 130, respectively, and these amplifiers are coupled in series with leads 101 through conductors 131-138 inclusive. Variable resistances 139, 140, 141 and 142 may be in circuit with the amplifiers to adjust the balance between relays 53, 55 and 56, which control motor 54 (which regulates the position of the cutting tool with respect to the reproductive bed). Motor 54 is connected to a lead 101 by a wire 143 and is coupled to a double pole, double throw, normally open relay 53 by conductors 144, 145. Relay 53 has its solenoid 53a energized through conductors 146, 147 joined to conductors 136, 132, respectively. A relay 55 is coupled to conductors 134 and 132 by a conductor 148. This same relay, which controls the up motion of the cutting tool (through motor 54) is connected to relay 53 by a wire 149 and to a lead 101 by another wire 150. Relay 56, which controls the down motion of the cutting tool, is connected to relay 53 through wire 151 and to conductors 132, 138 by conductor 148a. Another conductor 152 connects relay 56 with a lead 101. Thus relays 55, 56, which are normally closed, may open alternately when electric current flows through their solenoids, provided relay 53 is energized, to cause rotation of motor 54 to effect vertical movement of the carving tool. If photocells 45 and 49 are in an intensity balance, then there is an electrical balance conductor 136 and 132, therefore no current flows in conductors 146, 147 and relay 53 remains open, so that motor 54 is not energized. If, however, photocells 45 and 49 are not in an intensity balance, then conductors 136, 132 have a difference in potential and a current flows through conductors 146, 147 and the coil 53a of relay 53 to close the relay. Now, since the point of light which balanced photocell 45 to 49 must pass by photocell 50 or 48, according as the land profile is rising or declining, this will leave either relay 56 or 55 de-energized, which will operate motor 54 in the corresponding direction.

When using nontransparent objects such as photographic prints, the unit photocells are constructed as shown in Fig. 7, with photocell 155 at the end of a light-tight casing 156 and a mirror 157, with 50% reflectance, set at an angle of 45° relative to the longitudinal axis of casing 156. A converging lens 158 is so located as to focus rays of light reflected by mirror 157 from lamp 159 on a narrow aperture 160 at the end of the casing. Lamp 159 may have a reflector 161 to concentrate its rays on converging lens 162 which focuses the rays on the mirror. The light rays passing through aperture 160 are reflected

by the surface of the nontransparent print 12 and pass back through the mirror to the photocell 155, which is activated accordingly. The three-cell unit for use with photographic prints will consist of three units like the one of Fig. 7.

It will be clear that many different arrangements may be made to accomplish the results of the invention. If the reproductive bed is laminated with paint or other contrasting color layers at regular intervals, the cutting tool will form a relief map with contour lines appearing at the proper points. After the reproductive bed has been carved in accordance with the inventive process, it may be photographed orthographically and a map with contour lines will be produced. The apparatus may be useful in detecting camouflaged areas and in preliminary mapping for aerial bombardments. With slight modification, the apparatus can be made to work from oblique photographs. The stereos may be positives, positive transparencies, or negatives. Change from intaglio to relief type reproductions may be made by interchanging conductors 144, 145 on motor 54 and changing the position of the reproductive bed with relation to the datum plane. The carved bed may have its surface hardened by layers of shellac or metal deposited electrolytically, and in other ways, and may then be used as a master mold for the reproduction of like objects by stamping, pressing or casting. Many other details may be modified within the scope of the appended claims, and other uses for the apparatus will suggest themselves.

What I claim is:

1. A stereoscopic modeling machine for reproducing in three dimensions on a reproductive bed the contour of an object photographed stereoscopically, comprising, in combination, supporting means for a pair of stereoscopic photographs; carving means for cutting into the reproductive bed; power driven means for moving the carving means across the face of the reproductive bed longitudinally; means actuated when the carving means has completed its transit across the face of the reproductive bed to cause the carving means to move through a small increment laterally or at right angles to the first transit and then start another transit across the face of the reproductive bed in a path parallel to the first transit but in the opposite direction; said last named means then causing another small movement parallel to the first-named small increment and in the same direction; the carving tool thus moving over substantially the entire surface of the reproductive bed; a photoelectric cell circuit comprising a photocell which is moved synchronously with the carving tool adjacent to one of the stereos and a set of several photocells which is movable with the carving tool but adjacent to the second stereo; a mounting for the set of photocells permitting small movements thereof independent of any lateral or longitudinal movement of the carving tool; means responsive to the varying densities of points on the two stereos to cause the photocell set to automatically center itself over points in the second stereo which exactly correspond in density to points in the first stereo; the circuit containing said photocells being electrically balanced when the photocell set is exactly centered as described; means for mounting the carving tool to permit movement thereof substantially at right angles to the surface of the reproductive bed; and means mechanically connecting the set of photocells with the carving tool mounting

means to translate the independent small movements of the set of photocells into movements of the carving tool to cut into the reproductive bed proportionately to the independent displacements of the photocell set.

2. The invention according to claim 1, wherein the set of photocells comprises three cells in a row, and the photocell which is moved over the first stereo is exactly lined up with the photocells in the set, so that when the carving tool effects a transit from end to end of the reproductive bed, the photocells likewise move in the same straight line path over the respective stereos; the middle photocell of the set always tending to move toward the point in the second stereo which equals in density the corresponding point in the first stereo; movement of the set in either direction being initiated by a corresponding outer photocell of the set.

3. The invention according to claim 1, wherein there is an electric motor for continuously driving the carving tool and another electric motor for causing the carving tool to make the several transits across the face of the reproductive bed; a self-synchronous motor driving means to effect said small increments of lateral movement at the end of each transit; a pair of limit switches being in circuit with the self-synchronous motor and being closed alternately at the end of each transit to energize the self-synchronous motor; and another self-synchronous motor providing the power to translate the movement of the set of photocells, as it seeks the electrically balanced position, into proportionate or equal movements of the carving tool at right angles to the reproductive bed.

4. A stereoscopic modeling machine for reproducing in three dimensions on a reproductive bed the contour of an object photographed stereoscopically, comprising, in combination, a table; a slide rest slidably mounted on top of the table; a tool support slidably mounted on top of the slide rest but movable at right angles to the movement of the slide rest relative to the table; a cutting tool; means supporting the cutting tool on the tool support so that it may not only partake of the movements of the tool support in two directions parallel to the table top but may also move at right angles to the table top; power means to actuate the cutting tools, whatever its position or movement; power-actuated means to move the tool support relative to the slide rest and in opposite directions; power-actuated means to move the slide rest in small increments at the end of each movement of the tool support in either direction; a motor having means to effect movements of the cutting tool at right angles to the reproductive bed; light-sensitive means capable of comparing densities of points on two stereos and adapted to close electric circuits to effect movement of said motor in one direction or the other; the amount of said movement being proportional to the displacement along the axis of separation of corresponding points of the two stereos, so that the reproductive bed is carved proportionately to the differences between the stereo pair.

5. A machine of the character described comprising, in combination, a cutting tool adapted to carve a reproductive bed in relief or in intaglio; power means adapted to move the cutting tool over the entire surface of the reproductive bed; mounting means for the cutting tool permitting movements of the cutting tool substantially at right angles to the surface of the reproductive

bed; power means to drive the cutting tool, whatever its position; light-sensitive means coupled in a circuit, said circuit including means to move the cutting tool at right angles to the surface of the reproductive bed and independently of all other means; means to move the light-sensitive means; said light-sensitive means automatically comparing light values of two points on two stereos and automatically moving toward the position wherein the coupled circuit is balanced; and means connecting said light-sensitive means with the cutting tool mounting means so that movements of the light-sensitive means effect the aforesaid independent movements of the cutting tool.

6. A completely automatic machine for carving a reproductive bed in three dimensions to reproduce, on any desired scale, the contour of a stereoscopically photographed object, comprising, in combination, a cutting tool adapted to travel across the entire surface of reproductive bed; power means to drive the cutting tool and other power means to effect the travel thereof; light-sensitive analyzing means adapted to travel across the surfaces of a pair of stereoscopic photographs and to compare light densities of corresponding points of said pair; said analyzing means having movements independent of all other movements of the apparatus; circuits and also a motor controlled by the circuits to move the analyzing means to such a position that an electrical balance is effected in said circuits at the moment when points of exactly equal density in the stereo pair are exposed to the analyzing means; the electrical balanced condition effecting stoppage of the independent movements of the analyzing means; and means electrically and mechanically connecting the analyzing means with the cutting tool to effect in and out movement thereof rel-

ative to the reproductive bed, whereby the differences in elevation as recorded on the stereo pair are faithfully reproduced, on the aforesaid scale, during carving of the reproductive bed.

5 7. In combination with a pair of stereoscopic images of an object to be reproduced by carving a reproductive bed in relief or in intaglio, a scanning device comprising power-driven means and a plurality of photocells moved by the power-driven means over the images; circuits controlled by the photocells; said photocells being separated so that one photocell is moved over one image and the remaining photocells, comprising a set, are simultaneously moved over the other image
10 of the stereo pair; the photocell set comprising three juxtaposed photocells being constructed and arranged so that they will respond individually to the light density of three adjacent points in one straight line on the image; means for mounting the photocell set so that it may move
15 independently of all other parts of the apparatus; power means controlled by the photocells to move the photocell set; the middle photocell of the set tending always to seek the point in the second image of the stereo pair which exactly equals in density a point on the first image; the two outer photocells, when excited by an unbalanced condition due to variations in density of the points picked up, closing said circuits to cause
20 the middle photocell to seek the light-equilibrium position; a power-driven cutting tool; and means mechanically connecting the set of photocells with the cutting tool to cause the latter to move in and out of the reproductive bed equal to or
25 proportionately to the amount of movement of the photocell set in reaching the light-equilibrium position.
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