United States Patent

Webster

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[54] **VARIABLE APERTURE PHOTOEXPOSURE DEVICE**

[72] Inventor: **Ronald B. Webster,** Melrose, Conn.

[73] Assignee: **The Gerber Scientific Instrument Company,** South Windsor, Conn.

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[52] **U.S. Cl.**..**95/1 R,** 95/12

[51] **Int. Cl.**..**G03b 29/00**

[58] **Field of Search**.......95/12, 4.5, 1 R, 64; 346/107

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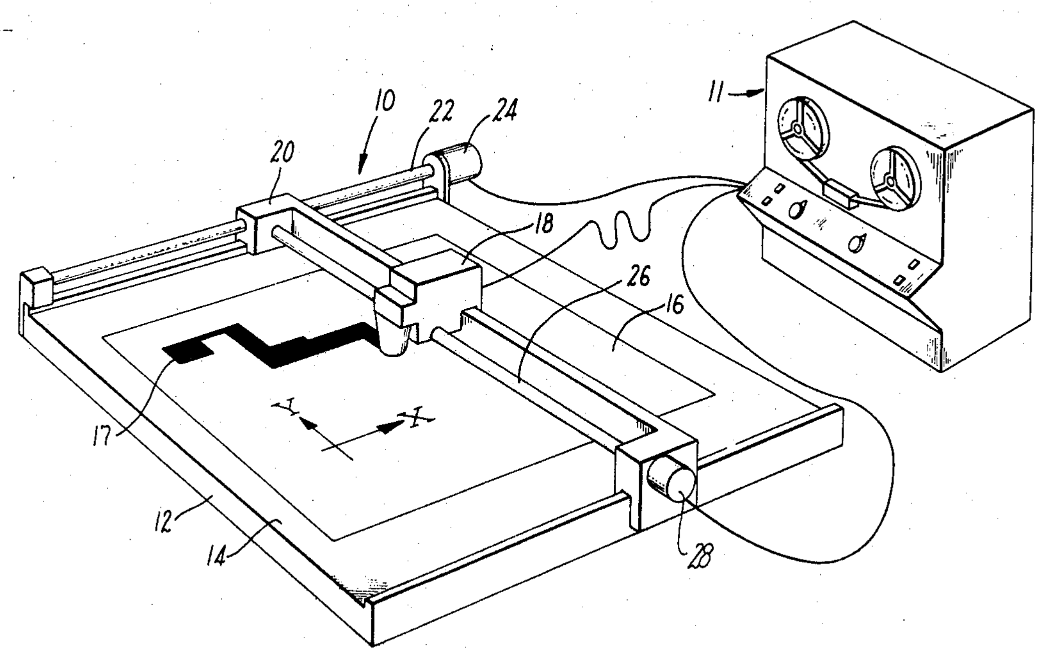
Primary Examiner—John M. Horan
Assistant Examiner—Kenneth C. Hutchison
Attorney—McCormick, Paulding & Huber

[57] **ABSTRACT**

In a photoexposure device for exposing lines on a photosensitive surface a rectangular aperture is used to form a rectangular spot of light projected onto the photosensitive surface and moved thereover to generate a line. During the exposure of a given line, the light spot is moved relative to the photosensitive surface in accordance with a velocity program which includes an acceleration stage at the beginning of the line, a deceleration stage at the end of the line, and possibly a constant velocity stage between the acceleration and deceleration stages. The width of the light spot, as measured in the direction of its travel, is varied in accordance with its velocity relative to the photosensitive surface to obtain distinct definition of the line at its ends and to obtain a substantially uniform exposure of the line along its length despite the changes in the velocity of the light spot. In one embodiment a pair of blades sliding in perpendicular directions form a variable aperture to determine the size and shape of the light spot. In another embodiment the source of light is a cathode ray tube, and the shape of the projected light spot is determined by the image on the face of the tube.

7 Claims, 10 Drawing Figures



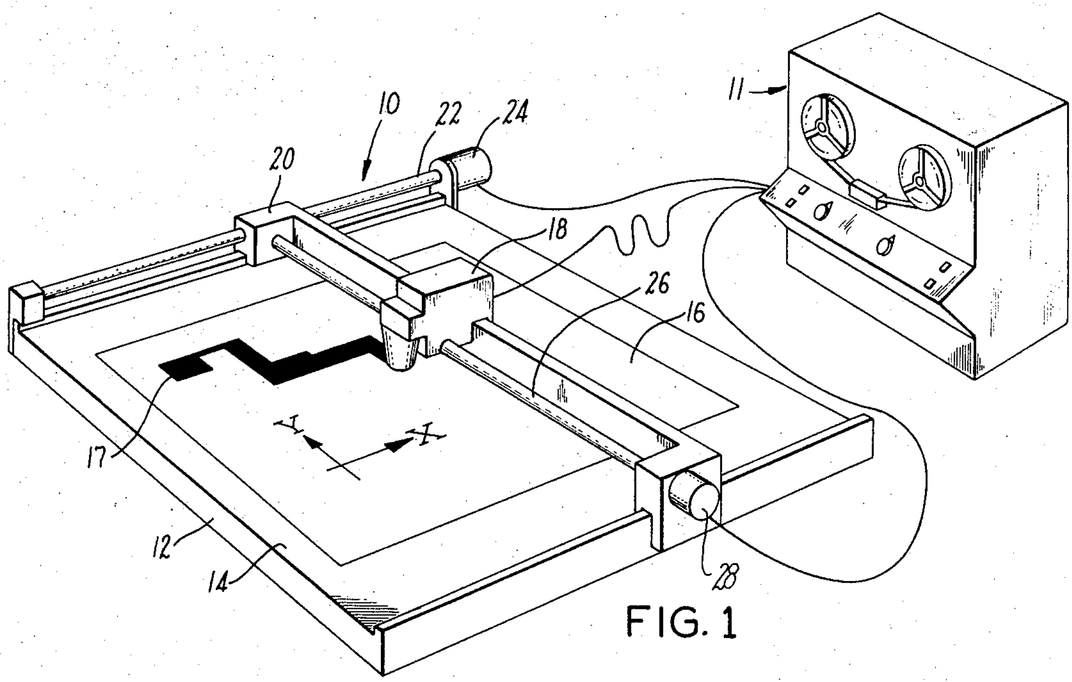


FIG. 1

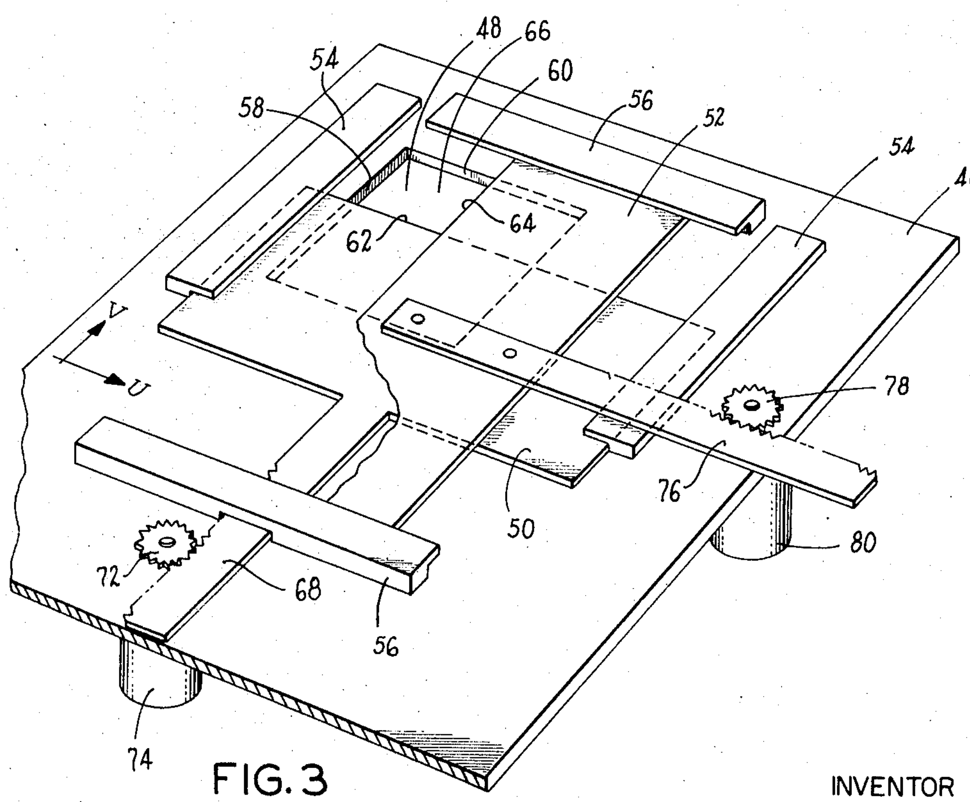


FIG. 3

INVENTOR
RONALD B. WEBSTER

BY McCormick, Paulding & Huber
ATTORNEYS

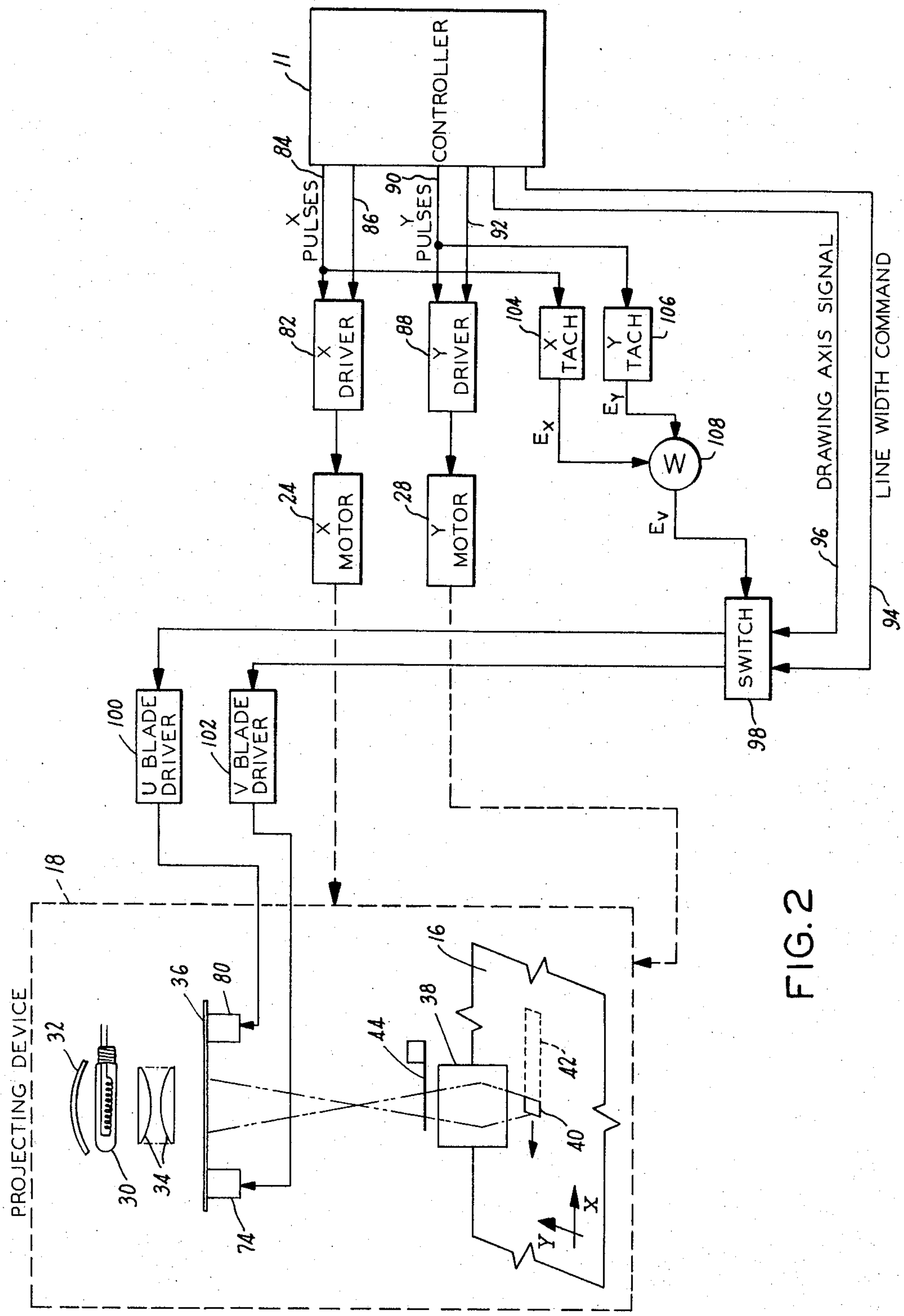

CONTROLLER
X PULSES
Y PULSES
X DRIVER
Y DRIVER
X TACH
Y TACH
X MOTOR
Y MOTOR
W
DRAWING AXIS SIGNAL
LINE WIDTH COMMAND
SWITCH
U BLADE DRIVER
V BLADE DRIVER
PROJECTING DEVICE
Y
X

FIG. 2

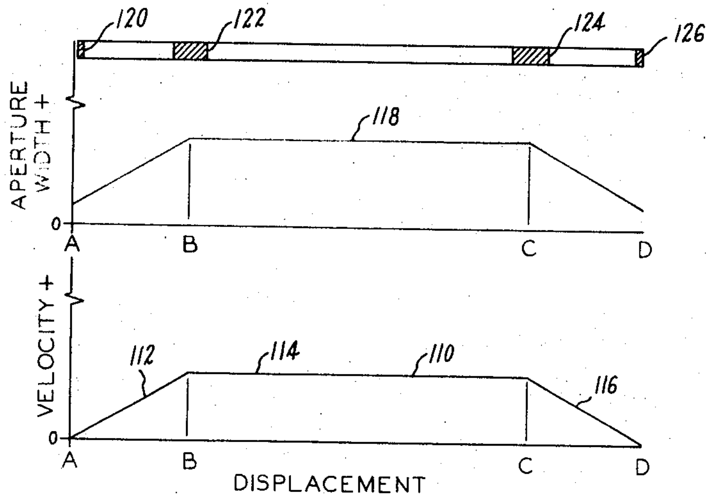


FIG. 4

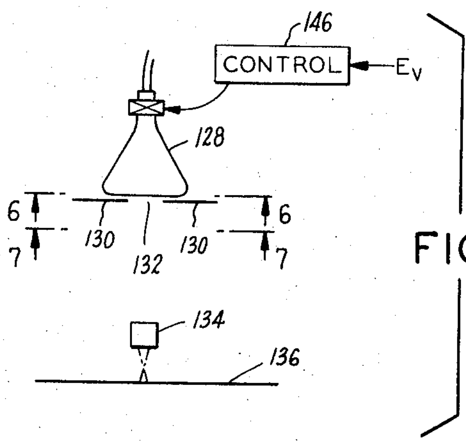


FIG. 5

FIG. 6

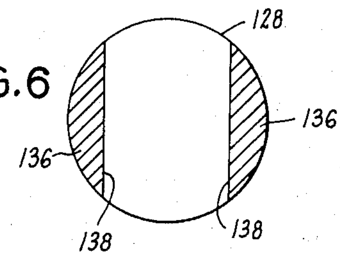
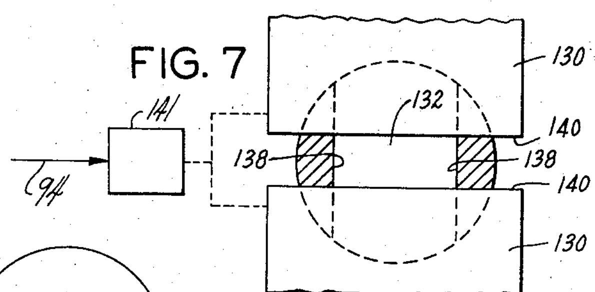


FIG. 7



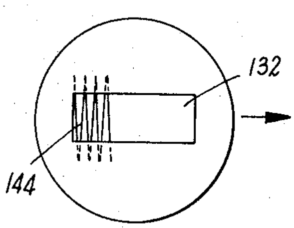


FIG. 8

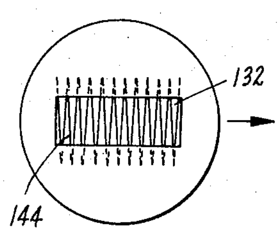


FIG. 9

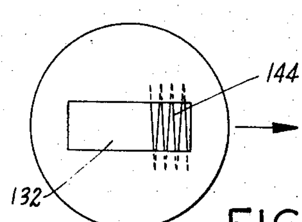


FIG. 10

VARIABLE APERTURE PHOTOEXPOSURE DEVICE

BACKGROUND OF THE INVENTION

This invention relates to photoexposure devices of the type which projects a spot of light onto a photosensitive surface and which spot of light is moved relative to such surface to expose a line thereon.

Photoexposure devices of the type with which this invention is concerned have recently been employed to a large extent for producing master artwork or masks used in making printed circuit boards, integrated circuit elements, and the like. They are not, however, limited to this use and may be employed in making other items as well. In such a device, the shape of the light spot projected onto the photosensitive surface for generating a line may take various different shapes, but commonly is either in the form of a circle or in the form of a rectangle. A circular spot of light has the advantage that it is highly symmetrical and may be moved in any direction without changing the width of the line being drawn. It has, however, the disadvantage that the light distribution across the width of the exposed line is elliptical rather than uniform with the edges of the generated line receiving a substantially lesser degree of exposure than the center of the line. A rectangular spot of light moved perpendicular to one of its edges provides a uniform distribution of light across the line being exposed. However, in order to prevent fade out or fuzziness at the ends of the exposed line, the aperture must be very narrow in the direction parallel to the path of travel, and this in turn requires that the spot of light either be moved at a very slow speed relative to the photosensitive surface or that an extremely brilliant lamp be used as the light source.

The general object of this invention is to provide a photoexposure device using a rectangular spot of light for generating a line on a photosensitive surface and which device is capable of generating high quality lines with distinct ends without being limited to operation at slow speeds or requiring unusually powerful light sources.

SUMMARY OF THE INVENTION

This invention resides in a photoexposure device which projects a spot of light onto a photosensitive surface and which is moved relative to the photosensitive surface to cause the light spot to move thereover and expose a line thereon. The light spot is of a rectangular shape and the means for forming this light spot is variable in two orthogonal directions to enable the size of the projecting light spot to be varied independently in both of its dimensions. Variation of the dimension perpendicular to the path of travel varies the width of the line generated. Variation of the dimension parallel to the line of travel varies the exposure or amount of light energy received by a given discrete area of the exposed line. A drive means connected with the projecting device, during the generation of a given line, drives the projecting device along a velocity program which includes an up-ramp at the beginning of the line, during which the velocity of the device is gradually increased, and a down-ramp at the end of the line, during which the velocity of the device is gradually decreased. A means connected with the drive means controls the dimension of the spot in the direction parallel to the path of travel so that such dimension is relatively small at low velocities and increases as the velocity increases.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of a photoexposure device embodying this invention.

FIG. 2 is a schematic diagram of the photoexposure device of FIG. 1.

FIG. 3 is a somewhat schematic perspective view showing the variable aperture mechanism used in the projecting device of FIG. 1.

FIG. 4 is a diagram in graphical form the manner in which the aperture width is varied with the velocity of the light spot.

FIG. 5 is a schematic diagram showing a portion of the projecting device of a photoexposure device comprising an alternative embodiment of this invention.

FIG. 6 is a view taken on the line 6—6 of FIG. 5 showing the face of the cathode ray tube as viewed from above the variable blades.

FIG. 7 is a view taken on the line 7—7 of FIG. 5 showing the face of the cathode ray tube from a point below the variable blades.

FIG. 8 is a view showing the trace of the cathode ray tube employed at or near the beginning of a line.

FIG. 9 is a view showing the trace of the cathode ray tube employed during the maximum velocity portion of the movement of the light spot during the generation of a line.

FIG. 10 is a schematic view showing the trace of the cathode ray tube employed at or near the end of a line.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Turning to the drawings and first considering FIGS. 1 to 3, these figures illustrate a photoexposure device embodying the present invention. As shown best in FIG. 1, the illustrated device comprises a mechanism 10 and an associated automatic controller 11. The mechanism 10 is made up of a table 12 having an upwardly facing supporting surface 14 for receiving a workpiece 16, such as a sheet of photosensitive paper, having a photosensitive surface on which it is desired to expose a given artwork, such as partially illustrated at 17, consisting of lines of different width. The exposure of the workpiece 16 is accomplished by a projecting device 18 which projects a spot of light onto the surface of the workpiece 16 and which is movable relative thereto to similarly move the projected spot of light thereover. The projecting device 18 is supported by a carriage 20 which straddles the table 12 and which is guided for movement relative thereto in the illustrated X coordinate direction. Movement of the carriage 20 in the X coordinate direction is provided by a lead screw 22 drivingly engaged with the carriage 20 and driven by a motor 24, preferably a step motor. The projecting device 18 is in turn movable relative to the carriage 20 in the illustrated Y coordinate direction and is driven in such direction by a lead screw 26 and associated motor 28, also preferably a step motor. The controller 11 may take various different forms, and may for example operate in response to input information on a punched paper tape to supply appropriate drive signals to the motors 24 and 28 to move the device 18 along the line to be generated. It also supplies other control signals to the projecting drive 18 to, among other things, control the size of the projected light spot as hereinafter described.

For the sake of simplicity, the device shown in FIG. 1 is one wherein the projecting device 18 is moved only in one coordinate direction at a time. That is, in drawing any given line, it is moved either in the X coordinate direction or in the Y coordinate direction, and it is therefore not adapted for drawing lines at any given slope. Photoexposure devices for drawing lines at a slope are, however, well known and it will be obvious that the general concept of this invention may be applied to such devices as well as the one illustrated.

Referring to FIG. 2, the projecting device 18 includes a light source 30 in the form of an incandescent lamp located between a mirror 32 and a pair of condenser lenses 34,34. Light from the lamp 30, and from the mirror 32, is collected by the condenser lenses 34, 34 and directed through an aperture in an aperture mechanism 36. A projecting lens system 38 in turn projects an image 40 of the aperture onto the surface of the workpiece 16. As shown, the image 40 constitutes a rectangular light spot, and as it is moved over the surface of the workpiece 16 in the direction of the arrow it exposes thereon a line 42 of a width equal to its dimension in the direction perpendicular to its path of movement. A shutter 44 between the aperture mechanism 36 and the projecting lens system 38 is movable into and out of the path of the light rays, by control signals from the controller 11, to turn the light spot 40 "on" and "off" as desired.

The aperture mechanism of FIG. 2 is shown in more detail in FIG. 3 and includes a base plate 46 having a large square opening 48 formed therein. On top of the base plate 46 and partially covering the opening 48 are two movable blades 50 and 52. The blade 50 is guided for movement in the illustrated V coordinate direction by two guides 54,54, and the blade 52 is movable in the illustrated U coordinate direction by two other guides 56,56. The two edges 58 and 60 of the opening 48 are parallel to the V and U coordinate directions respectively, and the two edges 62 and 64 of the blades 50 and 52 are like wise respectively parallel to the U and V coordinate directions. Accordingly, the edges 58, 60, 62, and 64 collectively define a rectangular aperture 66, the size of which may be varied in either dimension by moving the blades 50 and 52. Movement of the blade 50 in the V coordinate direction is effected by a rack member 68 fastened to the blade 50, the teeth of the rack member meshing with a pinion 72 on an associated drive motor 74. Likewise, the blade 52 is driven in the U coordinate direction by a rack member 76 connected to its upper surface and having its teeth meshing with the pinion 78 of an associated drive motor 80.

The aperture mechanism is so positioned relative to the remainder of the projecting device that the U coordinate axis is parallel to the X coordinate axis of the workpiece 16 and the V coordinate axis is parallel to the Y coordinate axis of the workpiece 16. Therefore, when the projecting device is moved in either the X or the Y coordinate direction, the light spot 40 is moved so that two of its edges are perpendicular to the path of movement and its other two edges are parallel to the path of movement. Accordingly, by moving one of the blades 50 and 52, the dimension of the light spot 40 perpendicular to its path of movement may be varied to vary the width of the line generated, and by moving the other of the blades, the dimension of the light spot 40 parallel to the path of movement may be varied to vary the amount of light energy received by a given discrete area of the work surface as the light spot passes thereover.

As shown in FIG. 2, the projecting device is driven in the X coordinate direction by the X motor 24 which is energized by an X driver 82. The driver 82 receives drive pulses from the controller 11 over the line 84 and also receives a direction signal from the controller over the line 86. Each time a pulse is received by the X driver 82 from the line 84, the driver 82 acts to change the state of energization of the step motor 24 to cause it to move through one step and move the projecting device one increment in the X coordinate direction, the direction of movement of the motor 24 being determined by the nature of the direction signal appearing on the line 86. In a similar fashion the projecting device 18 is driven in the Y coordinate direction by the Y motor 28 which is controlled by a Y driver 88 which receives drive pulses from the controller 11 over the line 90 and a direction signal from the controller on the line 92.

For the purpose of controlling the width of the line 42 exposed by the projected light spot 40, the controller 11 also produces an output signal on the line 94, commanding a desired line width. Another signal appearing on the line 96 represents the drawing axis, that is, the coordinate axis along which the light spot 40 is moved. The drawing axis signal on the line 96 controls a switch or gate 98 which transfers the line width command signal on the line 94 to either a U blade driver 100 or a V blade driver 102, depending on whether the light spot 40 is to be moved along the X or the Y coordinate axis. If the drawing axis signal indicates that the light spot is to be moved along the X axis, the switch 98 is conditioned to transfer the line width command signal from the line 94 to the V blade driver 102. On the other hand, if the drawing axis signal on the line 96 indicates that the light spot 40 is to be moved along the Y coordinate axis, the switch 98 is conditioned thereby to transfer the line width command signal from the line 94 to the U blade driver 100. The U blade driver 100 controls the energization of the motor 80 for positioning the blade 52, and the V blade drive controls the motor 74 for positioning the blade 50. The operation is such that, for each of the drivers 100 and 102, as the signal from the switch 98 is increased the associated blade 50 or 52 is moved to increase the size of the aperture 66 in the dimension controlled by the blade.

For the purpose of varying the size of the light spot 40 in the dimension parallel to its path of movement, and in accordance with its velocity relative to the workpiece 16, the device of FIG. 2 includes a means for producing a signal directly related to the speed of the light spot. This signal producing means may take various different forms, but in the illustrated case includes an X tachometer 104 and a Y tachometer 106. The X tachometer has as an input thereto the pulses appearing on the line 84 and it operates to produce an output signal E_X directly related to the repetition rate of such pulses and therefore directly related to the speed of the light spot **40** in the X coordinate direction. Likewise, the Y tachometer **106** has as an input thereto the Y pulses appearing on the line **90** and acts to produce an output signal E_Y directly related to the repetition rate of such pulses and therefore directly related to the speed of the light spot **40** in the Y coordinate direction. The outputs of the two tachometers **104** and **106** are transmitted to a summing device **108** to produce an output E_v transmitted to the switch **98**. Since, as previously mentioned, the projecting device **18** is moved only in one coordinate direction at a time, one or the other of the two signals E_x and E_y will always be zero and the output signal E_v will be equal to the other of the two signals E_x, E_y. That is, if the light spot is moved in the X coordinate direction, the E_v will be equal to E_x which represents the speed of the light spot in the X coordinate direction, and if the light spot is moved in the Y coordinate direction, E_v will be equal to E_y representing the speed of the light spot in the Y coordinate direction.

The switch **98** operates to transmit the signal E_v to the driver **100** or **102** other than the one which receives the line width command from the line **94**. More particularly, if the light spot **40** is moved in the X coordinate direction, then the signal E_v is transmitted to the U blade driver **100**, and if the light spot is moved in the Y coordinate direction, then the signal E_v is transmitted to the V blade driver **102**.

To consider the operation of the device of FIG. **2** assume that the light spot **40** is to be moved in the illustrated X coordinate direction as the result of X pulses produced by the controller on the line **84** to cause the X motor **24** to move the projecting device **18** in the X coordinate direction. The drawing axis signal applied to the switch **98** conditions the switch to transfer the line width command signal from the line **94** to the V blade driver to cause the projected light spot **40** to have the proper dimension perpendicular to the path of travel to produce the desired width of line **42**. At the same time as the X pulses appear, the signal E_v is transmitted through the switch **98** to the U blade driver to cause the light spot **40** to have a dimension parallel to its path of movement dependent on the value of the signal E_v. The signal E_v is in turn dependent on the velocity of the projecting device in the X coordinate direction. Therefore, when the speed of the projecting device is low, the signal E_v is correspondingly low and the V blade driver **102** and motor **74** act to position the blade **52** to produce a light spot **40** having a narrow dimension parallel to the X axis. As the speed of the light spot increases, the signal E_v increases and accordingly the V driver **102** and motor **74** operate to cause the light spot **40** to have a larger dimension in the direction of the path of travel.

FIG. **4** illustrates the relationship between the speed of the light spot and its dimension parallel to its path of movement. In this figure, the line **110** represents the velocity of the light spot as it is moved relative to the workpiece from a point A to a point D along a straight line. This program of velocity versus displacement is controlled by the controller **11** and includes an initial up-ramp portion **112** during which the spot is accelerated, an intermediate portion **114** during which the spot is held at a substantially constant velocity, and a final down-ramp portion **116** during which the spot is decelerated. In the illustrated case, the ramp portions **112** and **116** are linear, but this is not necessary, and the ramp portions may also take non-linear characteristics, if desired. Also, in moving between two closely spaced points, the light spot may not meet the maximum velocity represented by the intermediate portion **114** and the velocity versus displacement profile may in some cases consist merely of an up-ramp followed by a down-ramp.

The line **118** of FIG. **4** represents the manner in which the aperture width is varied in the direction parallel to the path of movement of the light spot as the light spot is moved from the point A to the point D. More particularly, at the beginning of the line (point A) the aperture has a minimum width, and as the speed of the light spot increases the width likewise increases during the up-ramp portion of the movement. During the intermediate portion of the movement the aperture width remains constant, and during the down-ramp portion of the movement the aperture width decreases until reaching the final point D at which it is returned to its minimum dimension.

The upper portion of FIG. **4** shows schematically the nature of the projected light spot as it moves from the point A to the point D. More particularly, the reference numeral **120** indicates the shape of the light spot at the point A. The reference numeral **122** represents the shape of the light spot at its maximum width at the end of the up-ramp portion **112** (point B). Reference numeral **124** shows the shape of the light spot at the beginning (point C) of the down-ramp portion **116**, and the reference numeral **126** shows the shape of the light spot at the point D. It will of course be understood that as the light spot moves from the point A to the point B it gradually increases in size from that shown at **120** to that shown at **122**. As it moves from the point B to the point C, it remains at a constant size, and as it moves from the point C to the point D, it gradually decreases in size from that shown at **124** to that shown at **126**.

The result of the aforegoing change in width of the aperture as it moves from the point A to the point D is the production of a high-quality line of the workpiece **16** after the workpiece is run through the normal photographic development process following the exposure. That is, the line may be made to have very sharp and distinct side edges as well as end edges. The distinctness of the side edges is due to the fact that the line is uniformly exposed between its side edges with the photosensitive surface receiving as much light energy near such edges as at the center of the line. Also, the line is uniformly exposed along its length despite changes in the speed of the light spot in moving between the ends, and at the ends of the line fade out or fuzziness is reduced by the fact of using a very narrow light spot.

FIGS. **5** to **10** show an alternative way of producing a variable dimension light spot for exposing a photosensitive surface in a device such as that of FIG. **1**. Referring first to FIG. **5**, this figure shows schematically a projecting device which may be used in the device of FIG. **1** in place of the projecting device **18** of FIG. **2**. More particularly, this projecting device comprises a cathode ray tube **128** and two movable blades **130, 130** which control the dimension of the aperture in one coordinate direction, the aperture being indicated at **132**. The beam of the cathode ray tube is swept across the aperture to illuminate at least a portion thereof and a projecting lens system **134** projects an image of the illuminated portion of the aperture onto the photosensitive surface of the workpiece **16** to produce the line drawing light spot **40**.

FIG. **6**, in a scale enlarged from that of FIG. **5**, shows the face of the cathode ray tube **128**, and on this face are two masks **136,136** having spaced edges **138,138**. The masks **136,136** are fixed relative to the cathode ray tube and may, for example, constitute layers of opaque paint. The movable blades **130, 130** are located beyond the fixed masks **136,136** and have edges **140,140** spaced from one another and arranged perpendicular to the edges **138, 138**. Therefore, the edges **138, 138, 140** and **140** in combination define a rectangular aperture **132** the dimension in one coordinate direction of which is variable by varying the spacing between the blades **130, 130**. The blades **130, 130** determine the width of the exposed line and suitable means **141** is provided for moving them relative to one another in response to the line width command signal.

FIGS. **8, 9**, and **10** show the aperture **132** as illuminated by the beam of the cathode ray tube at various times during the movement of the projected light spot along a line to be exposed. In these figures, the scan of the beam is indicated at **144** and the direction in which the projected light spot is moved relative to the photosensitive surface is represented by the arrow in each figure.

FIG. **8** shows the condition of the cathode ray tube at the beginning of a line at which time the light spot is moved at a slow rate of speed. It will be noted that at this time, the scan **144** of the beam is such as to cover and illuminate only a small portion of the left-hand side of the aperture **132**. Therefore, the projected light spot has a similar narrow width in the direction of movement of the light spot. FIG. **9** shows the condition of the aperture **132** at maximum speed of the projected light spot, and at this time, the scan **144** completely covers the aperture so that the projected light spot has a maximum width in the direction of movement. FIG. **10** shows the condition of the aperture **132** at the end of the line to be exposed. At this time the scan **144** of the beam covers only a small portion of the right-hand side of the aperture **132** and therefore the projected light spot has a correspondingly narrow width in the direction of movement of the projected spot relative to the photosensitive surface.

Of course, the amount of the aperture **142** covered by the scan **144** of the beam is controlled in accordance with the velocity of the light spot relative to the photosensitive surface as by, in FIG. **5**, a deflection control means **146** responsive to the speed signal E_v. As represented in FIG. **5**, the illustrated device is adapted for drawing lines in one coordinate direction only, however, drawing in two coordinate directions or at a slope may easily be accommodated by using a suitable means, such as a dove prism in the light path between the cathode ray tube and the photosensitive material **16**, for rotating the projected light spot in accordance with changes in its direction of movement to maintain the edges thereof defined by the edges **140, 140** of the blades **130, 130** parallel to its path of travel.

I claim:

1. A photoexposure device for exposing a line on a photosensitive surface by means of a light spot moved thereover, said photoexposure device comprising means for supporting a workpiece having a photosensitive surface, a projecting device for projecting a light spot onto the photosensitive surface of a workpiece supported by said supporting means, and means for moving said light spot relative to said photosensitive surface for exposing a line thereon, said projecting device including a light source, aperture means defining a rectangular aperture illuminated by said light source, means for projecting an image of said aperture onto said photosensitive surface to form said light spot, and means for varying the size of said aperture in only one dimension thereof in response to changes in the speed of said light spot relative to said photosensitive surface.

2. A photoexposure device as defined in claim **1** further characterized by said means for varying the size of said aperture in one dimension thereof in response to changes in the speed of said light spot relative to said photo-sensitive surface being such that the variation of said size in said one dimension corresponds to changes in the size of said light spot in the dimension parallel to its path of movement relative to said photosensitive surface and such that said size of said one dimension is decreased as said speed of said light spot is decreased and is increased as said speed of said light spot is increased over a given range of speeds of said light spot.

3. A photoexposure device as defined in claim **2** further characterized by means for varying the size of said aperture in the other dimension thereof to vary the width of the line exposed on said photosensitive surface by movement of said light spot thereover.

4. A photoexposure device as defined in claim **1** further characterized by said aperture means including a base plate having an opening therein, a first blade partially covering said opening and having an edge defining one edge of said aperture, and means supporting said blade for movement relative to said base plate in a direction perpendicular to said one edge thereof, said means for varying the size of said aperture in one dimension thereof in response to changes in the speed of said light spot relative to said photosensitive surface including means for moving said first blade in the direction perpendicular to said one edge thereof in response to changes in the speed of said light spot relative to said photosensitive surface.

5. A photoexposure device as defined in claim **4** further characterized by said aperture means further including a second blade partially covering said opening in said base plate and having one edge thereof arranged perpendicular to said one edge of said first blade, means supporting said second blade for movement relative to said base plate in the direction perpendicular to its said one edge, and means for moving said second blade in said direction perpendicular to said one edge thereof to vary the size of said aperture in the other dimension thereof.

6. A photoexposure device as defined in claim **1** further characterized by said light source comprising a cathode ray tube having an output face, and said aperture means comprising a pair of fixed masks positioned adjacent said output face and collectively defining two spaced parallel edges between which said output face is unobstructed by said fixed masks, and second mask means positioned adjacent said output face and defining two spaced parallel edges oriented perpendicular to said spaced edges of said fixed masks and between which latter edges said output face is unobstructed by said second mask means so that said spaced edges of said fixed masks and said spaced edges of said second mask means collectively define a rectangular aperture adjacent said output face, and said means for varying the size of said aperture in one dimension thereof in response to changes in the speed of said light spot relative to said photosensitive surface comprising means for sweeping the beam of said cathode ray tube back and forth across said aperture in a direction generally perpendicular to said spaced edges of said second mask means to illuminate a portion of said aperture in the dimension thereof perpendicular to said spaced edges of said fixed masks and the length of which illuminated portion is dependent on the speed of said light spot relative to said photosensitive surface.

7. A photoexposure device as defined in claim 6 further characterized by said second mask means including at least one blade defining one of said spaced edges of said second mask means and movable relative to the face of said cathode ray tube in the direction perpendicular to said latter edge, and means for moving said at least one blade relative to said face of said cathode ray tube in said direction perpendicular to said latter edge.

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