

June 2, 1964

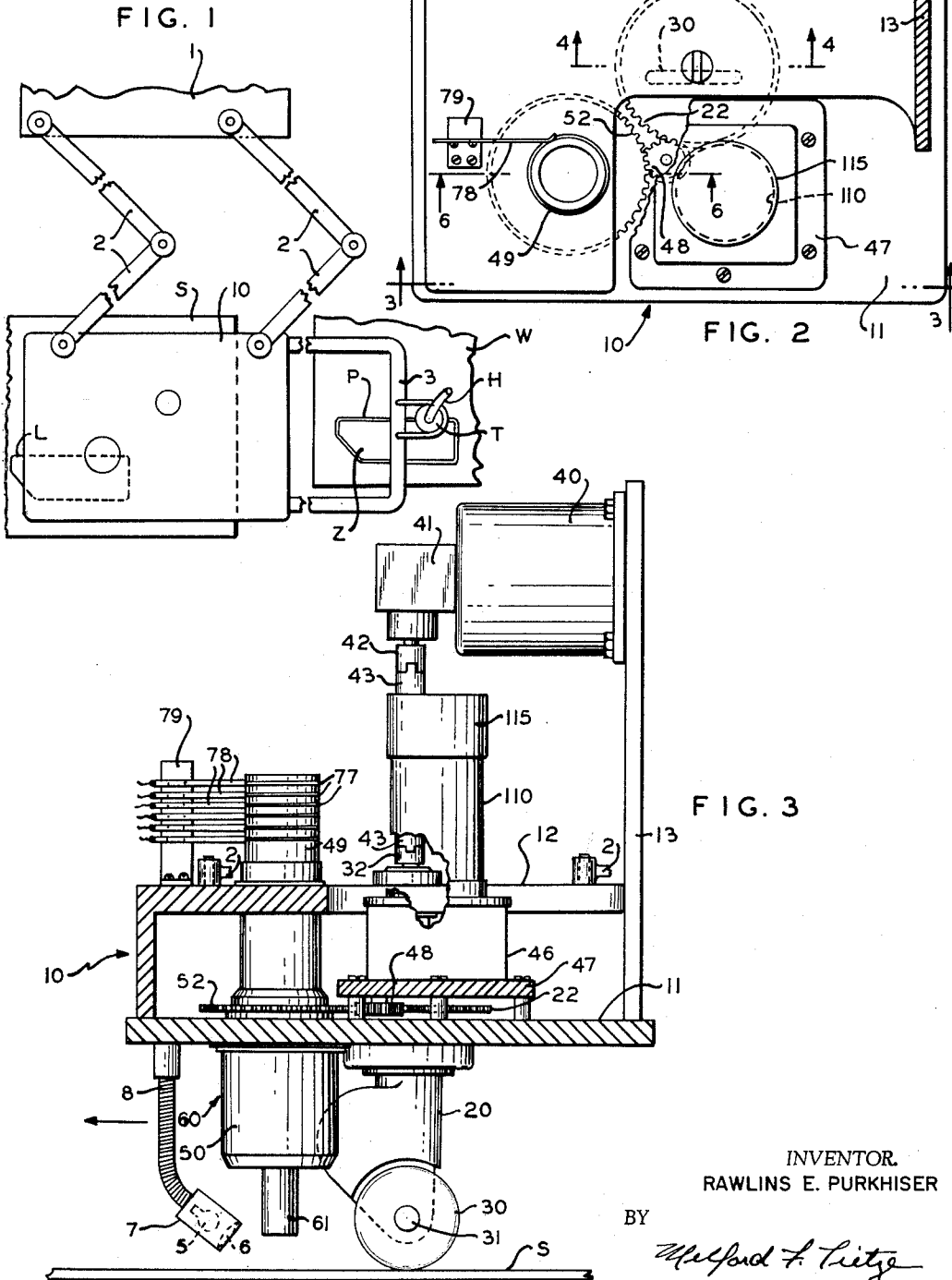
R. E. PURKHISER

3,135,904

PHOTOELECTRIC LINE OR EDGE TRACER

Filed Jan. 15, 1962

3 Sheets-Sheet 1



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June 2, 1964

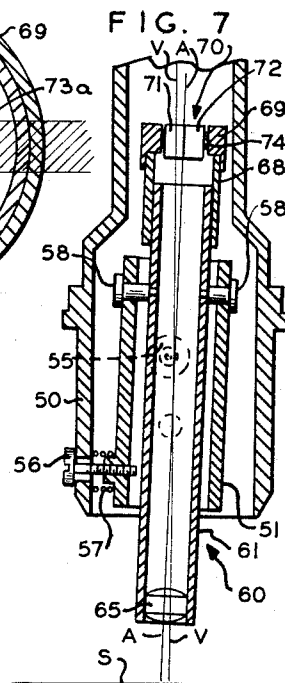
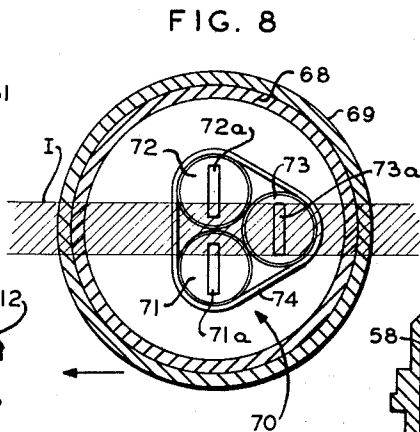
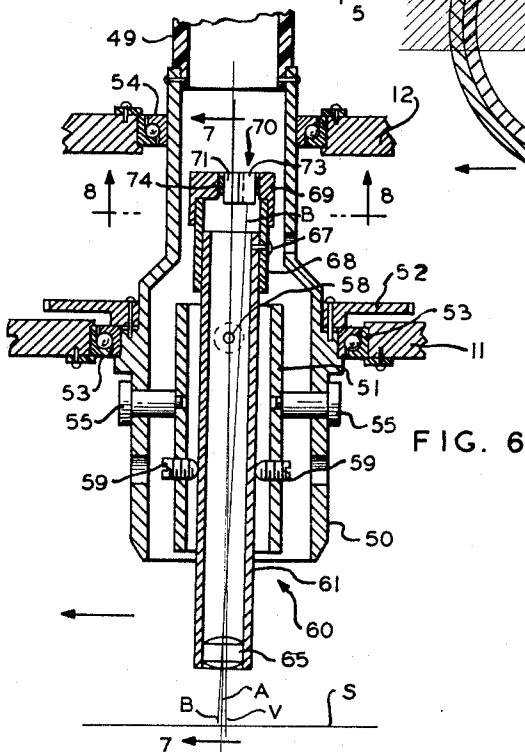
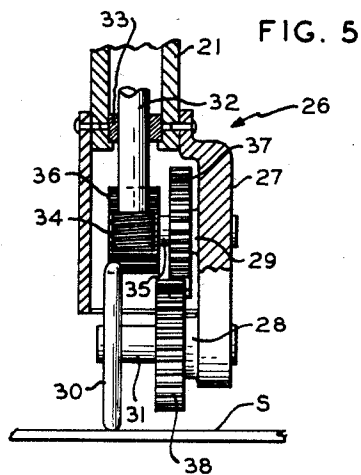
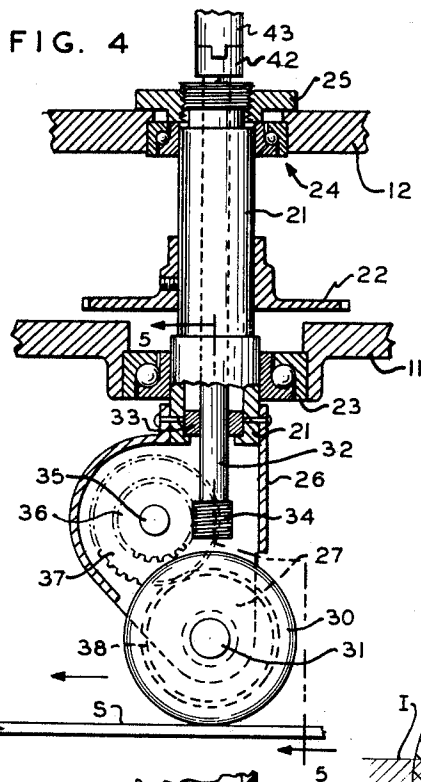
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PHOTOELECTRIC LINE OR EDGE TRACER

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3 Sheets-Sheet 2



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PHOTOELECTRIC LINE OR EDGE TRACER

Filed Jan. 15, 1962

3 Sheets-Sheet 3

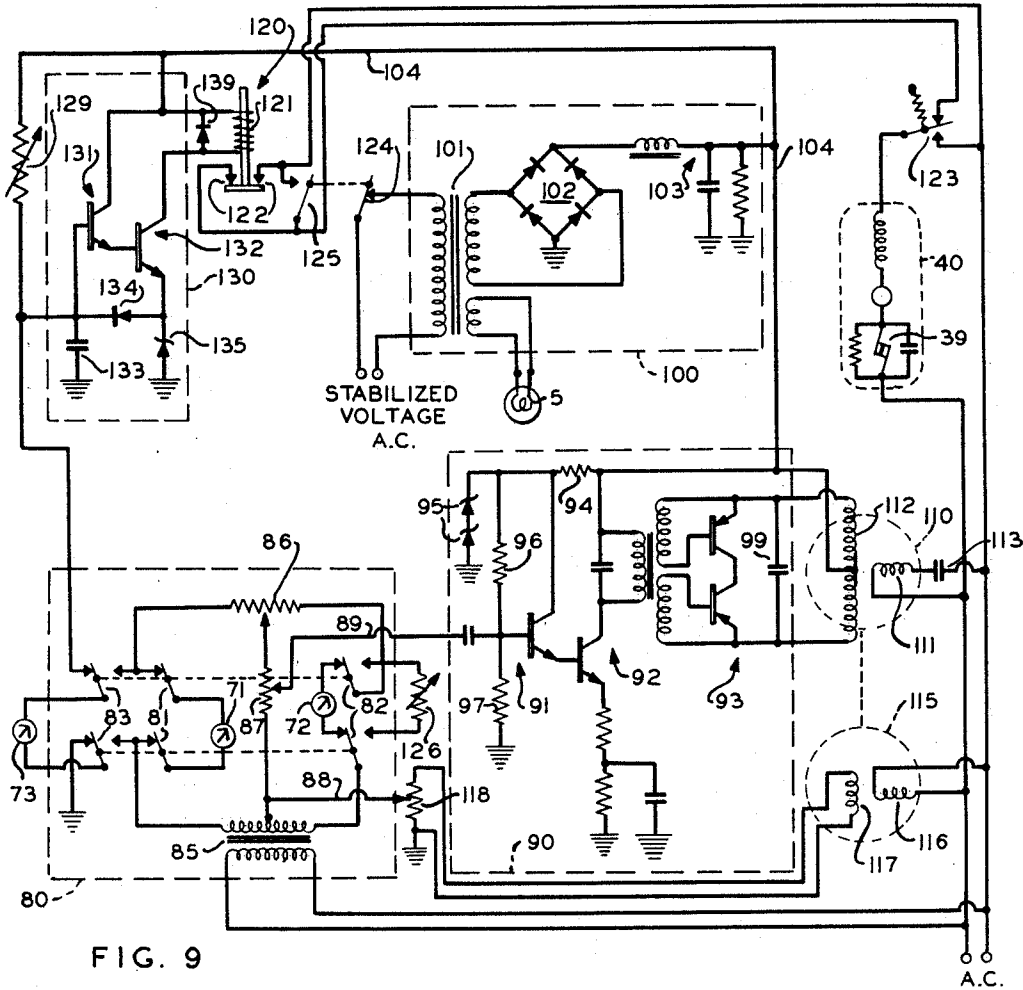


FIG. 9

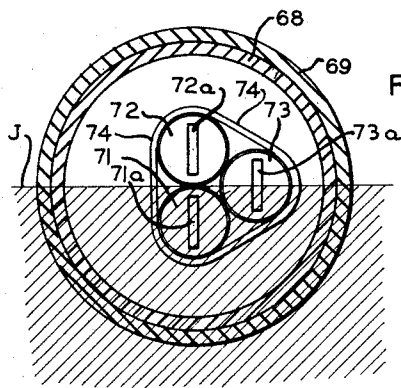


FIG. 10

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3,135,904

PHOTOELECTRIC LINE OR EDGE TRACER

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Filed Jan. 15, 1962, Ser. No. 166,085

16 Claims. (Cl. 318—31)

This invention relates to a tracer, and more particularly to one photoelectrically controlled by the indicium (e.g., line or edge) which it is to trace.

Tracers of this type have conventionally been relatively complex and at least in the case of line tracers less than fully dependable, and the definition and fidelity with which they trace an indicium have been substantially less than perfect. It is an object of the invention to provide a tracer of simplified construction which functions with improved dependability. It is another object to increase the definition and fidelity of tracing.

The indicia to be traced may be lines or edges (the latter being simply the demarcation between side-by-side dark and light areas), and it has been customary to construct a tracer either for the tracing of lines or for the tracing of edges. It is an object of the invention to provide a tracer which in an extremely simple manner may be converted from a line tracer to an edge tracer and vice versa. It is a further object to provide a tracer in which such conversion may be accomplished without the necessity to make mechanical readjustments.

In a line tracer there are desirably incorporated "off-line" means for stopping the operation (or giving a signal, or both) if and when through any maloperation the control by the line is lost. It is an object of the invention to provide improved "off-line" means of that nature. It is a further object to arrange the "off-line" means so that one of its components may advantageously be used for the control function in edge tracing (in which "off-indicium" means are not required).

Other and allied objects will appear from the following description and the appended claims.

In the preferred embodiment of the invention as arranged for line tracing a carriage is guided, over the surface which bears the line, under the control of a pair of mutually fixed photoelectric devices contained therein and onto whose light-sensitive areas there are optically projected the margins of an image of the line. These devices, which may be light-modulated resistors whose light-sensitive areas are of quite restricted dimension along the line or its image, are connected in a balanceable electric circuit to which A.C. is preferably applied and which produces an output of directivity and amplitude corresponding to the direction and degree of lateral displacement of the image. This output, preferably A.C., is amplified by a simple amplifier whose output in turn is supplied directly to servo motor which steers the carriage and maintains the pair of devices in proper angular orientation to the line. In converting the tracer from line to edge tracing there is substituted for one of the pair of devices a third photoelectric device and for the other of the pair a simple resistor; in line tracing this third device is preferably employed as part of the "off-line" means previously mentioned. The third device is displaced longitudinally from the pair of devices in a manner which renders unnecessary any readjustment of "lead" (a function hereinafter defined) in the conversion from line to edge tracing or vice versa; the third device is disposed laterally intermediate the pair of devices in a manner which renders unnecessary any readjustment of "kerf" (another function hereinafter defined) in such conversion.

In the detailed description of the invention hereinafter

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set forth reference is had to the accompanying drawings, in which:

FIGURE 1 is a plan view of a tracer in typical relationship to a surface S bearing an indicium L to be traced, to a fixed member 1, and to a tool T whose guidance may be the ultimate function of the tracing;

FIGURE 2 is an enlarged and more fully developed plan view of the tracer of FIGURE 1;

FIGURE 3 is a vertical cross-sectional view taken along the line 3—3 of FIGURE 2;

FIGURE 4 is an enlarged vertical cross-sectional view taken along the line 4—4 of FIGURE 2;

FIGURE 5 is a vertical cross-sectional view taken along the line 5—5 of FIGURE 4;

FIGURE 6 is an enlarged vertical cross-sectional view taken along the line 6—6 of FIGURE 2;

FIGURE 7 is a generally vertical cross-sectional view taken along the line 7—7 of FIGURE 6;

FIGURE 8 is an enlarged generally horizontal view taken upwardly along the line 8—8 of FIGURE 7 when the tracer is in process of tracing a line;

FIGURE 9 is a schematic diagram of the electrical circuits of the tracer; and

FIGURE 10 is a view similar to FIGURE 8 but taken when the tracer is in process of tracing an edge.

A typical organization of a tracer in which the invention may be incorporated is shown in FIGURES 1, 2 and 3. Therein 10 designates a carriage which is supported by a single upright traction wheel 30 (see FIGURE 3) pivoted on both horizontal and vertical axes. The carriage is freely movable, within limits, in translation in all horizontal directions over a surface S therebeneath on which the traction wheel 30 rests. The carriage is, however restrained against rotation parallel to that surface, and is restrained against any tilting from parallel to the surface S, in any suitable manner. By way purely of simple schematic illustration of means for exerting these restraints, FIGURE 1 shows a pair of strong and sturdily pivoted pantographic arms 2 pivotally connected to it and to a stationary member 1.

The immediate function intended to be performed by the carriage 10 is its movement over the surface S in a path corresponding to an elongated indicium (e.g. a line or an edge) appearing on the surface S; the ultimate function is the guidance of a tool (e.g. a metal-cutting torch) coupled to it in some suitable manner, over work to be operated on by that tool, in a path corresponding to that indicium. Thus in the schematic plan of FIGURE 1 the indicium appears as the line L; the tool appears as the torch T, supplied with fuel by the hose H, directly downwardly to propel its flame against work in the form of a plate W and, purely by way of example, coupled to the carriage by the rigid bracket 3 to which it is clamped; and the path to be traversed by the tool over the work—i.e., along which the flame projected by the torch will impinge on and cut through the work—appears as P, corresponding in configuration to the line L.

The carriage itself may comprise a main rectangular platform 11; a supplemental platform 12, for example generally L-shaped, secured in spaced relation to and above the platform 11; and a member 13 extending upwardly, for example at the righthand end of the platforms 11 and 12.

A mount 20 for the traction wheel 30 is journaled on a vertical axis in the platforms 11 and 12 to provide for the vertical-axis pivoting of the traction wheel. As best seen in FIGURES 4 and 5, this mount may comprise a relatively thick-walled tube 21 to which are secured one of the races of a ball bearing 23 of which the other race is secured to the platform 11, and one of the races of a

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ball bearing 24 of which the other race is secured to the platform 12. The bearings 23 and 24 resist upward thrust of the tube 21, which in the absence of that thrust may for example be retained therein by the large circular nut 25 locked on the tube 21 just above the platform 12. At the bottom of the tube 21 there may be secured to it a suitably shaped casting 26 whose principal portion is a downwardly extending vertical wall 27, more displaced from the axis of the tube than is the wall of the latter and provided near its bottom with a horizontal boss 28 extending toward that axis. The traction wheel 30 may be mounted on a shaft 31 journaled in that boss. Obviously the vertical plane in which the traction wheel is disposed may be swung about the axis of the mount 20 by angular movement of that mount in the bearings 23 and 24; this provides for steering of the carriage.

Propulsion of the carriage, by way of example in the direction indicated by the arrow in FIGURES 3, 4 and 6, is provided for by applying a rotating force about its horizontal axis to the traction wheel 30. This force may be conducted to the traction wheel through a shaft 32 coaxial with the tube 21 and journaled therewithin in suitable bearings of which the lower one only is shown as 33; this shaft may extend downwardly to a little above the traction wheel, and may there carry a worm 34. At the level of the worm the wall 27 may be provided with another horizontal boss 29, and in that boss there may be journaled a shaft 35 on which is secured a gear 36 engaged by the worm; there may also be secured on that shaft another gear 37 which peripherally engages a gear 38 secured on the wheel shaft 31. It will readily be understood that rotation of the shaft 32 will be transmitted, in stepped-down angular velocity, to the traction wheel through the succession formed by worm 34, gear 36, gear 37 and gear 38.

Rotation of the shaft 32, and thus rotation of the traction wheel and propulsion of the carriage, may be accomplished by a driving motor 40. Conveniently this may be mounted, with its main shaft horizontal, at the top of the carriage member 13 from which it may extend toward the axis of the wheel mount 20, and above that mount the motor may be provided with a gear box 41 from which there emerges a driving shaft 42 aligned with that axis. Coupling between the shaft 42 and the shaft 32 may be provided by an intervening vertical shaft 43 keyed to each.

So long as the mount 20 is not in process of being turned about its axis, and the carriage is therefore being propelled in a straight line, the rate of its propulsion as seen anywhere in the carriage system is constant, being uniquely determined by the speed of rotation of the driving motor 40 and the ratios of the gearing intervening between its main shaft and the wheel shaft 31. While the mount is in process of being turned about its axis, however, the rate of carriage propulsion as seen at the point of contact of wheel 30 with surface S will be temporarily increased or decreased (depending on the direction of the turn); it is nevertheless desirable for many purposes that the rate of carriage propulsion as seen at the axis of the mount 20 (and thus at any other point fixed within the carriage) still remain constant. This desideratum may be achieved by a suitably determined small offset of the plane of the traction wheel 30 from the axis of the mount 20, as fully described in U.S. Patent No. 2,461,585 issued, on application of Nelson E. Anderson, to the assignee of the present invention; such an offset is contemplated herein and a typical one has been illustrated in FIGURE 5.

In order to scan the elongated indicium L and thus to derive the intelligence for steering of the carriage so that the path of its movement over the surface S will correspond to the indicium, the carriage may incorporate an optico-electric system comprising photoelectric means and a lens for projecting an image of a longitudinal seg-

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ment of the indicium onto that means. At least the photoelectric means—and permissibly the entire optico-electric system—is made angularly movable about an axis normal to the surface S and thus parallel to the axis of the mount 20. In the illustrated embodiment the optico-electric system, designated generally as 60, is supported within a mount in the form of a vertical barrel 50 which (as better seen in the enlarged cross-sectional FIGURE 6) is journaled in the platforms 11 and 12. More specifically, the barrel 50 may be of greater diameter in its lower than in its upper portion; to journal it its lower portion may have clamped thereto one of the races of a ball bearing 53 of which the other race is clamped in the platform 11, while its upper portion may have secured thereto one of the races of a ball bearing 54 of which the other race is clamped in the platform 12.

Angular movements of the barrel 50 and of the mount 20 about their respective vertical axes are effected simultaneously and in equal direction, rate and degree. To effect these movements there is employed a servo motor 110, conveniently having a vertical main shaft; at its lower end this servo motor may rest on and be mechanically coupled into a reducing-gear box 46, at the bottom of which a flange 47 extends outwardly and may be supported above and with a small spacing from the platform 11. Downwardly from the gear box 46, for example near its left rear corner, there may extend a short output shaft carrying a relatively small diameter gear 48; this gear may engage relatively larger-diameter and mutually similar gears 22 and 52 respectively secured on the wheel mount 20 and the barrel 50 slightly above the platform 11, and will impart to those gears, in greatly reduced speed and amplitude, the angular motion engaged in by the shaft of the servo motor. The servo motor 110 is controlled, through electric circuitry and in a manner which are hereinafter set forth, by the photoelectric means comprised in the optico-electric system, of which system the preferred construction may now be described.

In connection with the description of the optico-electric system it should be noted that by reason of the gearing 48—22—52 the relationship of the angular positions of the wheel mount 20 and the barrel 50 to each other is uniquely predetermined. FIGURE 4 is a frontally viewed cross section of the mount 20 in a particular angular position—i.e., that arbitrarily assumed in the illustration of FIGURES 2 and 3—and it is helpful to observe that FIGURE 6, which shows the optico-electric system in detail and to which reference is now made, is a frontally viewed cross section of the system in the angular position it will occupy while the mount 20 occupies the angular position of FIGURE 4. Reference is of course simultaneously made to FIGURE 7, which is a generally laterally viewed cross section, as well as to FIGURE 8, which is an upwardly viewed and much enlarged cross section of the upper (or photoelectric) portion of the optico-electric system.

In the wall of the lower portion of the barrel 50 at an intermediate level therein, along a horizontal axis lying in the plane of FIGURE 6, there are secured a pair of inwardly directed studs 55 pointing toward each other, on whose inner end portions there is pivoted a generally vertical tube 51 of diameter appreciably smaller than the internal diameter of the barrel. By appropriate positioning of the tube 51 about its pivots its axis may be made vertical and coincident with that of the barrel 50; its axis may, however, be rocked appreciably away from vertical, and within limits any desired degree of divergence from vertical may be established by a suitable adjusting means. Such means has been shown in FIGURE 7 as an enlarged-head generally horizontal screw 56 passing through a suitable oversized hole near the bottom of the barrel 50, threaded into the tube 51 near its bottom, and surrounded by a helical spring 57 compressed between mount and tube. It will thus be understood that

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the adjusting screw 56 provides for limited orientation of the axis of tube 51 within a vertical plane at right angles to that of the wheel 30.

In the wall of the tube 51 near its top, along an axis normal to the axis of that tube and disposed in the plane of FIGURE 7, there are secured a pair of inwardly directed studs 58 pointing toward each other, on whose inner end portions there is pivoted the generally vertical external tubular member 61 of the optico-electric system 60. The tubular member 61 is of diameter appreciably smaller than the internal diameter of tube 51, and it may extend at both of its extremities beyond the extremities of that tube. By appropriate positioning of the tubular member 61 about its pivots its axis—which is the axis of the optico-electric system—may be made coincident with that of tube 51; its axis may, however, be rocked appreciably away from such coincidence, and within limits any desired degree of divergence from such coincidence may be established by a suitable adjusting means. Such means have been shown in FIGURE 6 in the form of a pair of set screws 59 threaded inwardly and toward each other through the wall of the tube 51 near its bottom, along an axis normal to the axis of the tube, each into abutment against the tubular member 61, the heads of these screws being accessible through suitable apertures in the barrel 50. It will thus be understood that the adjusting screws 59 provide for limited orientation of the axis of the tubular member 61 within a plane which contains the axis of tube 51 and is normal to the plane in which the tube-51 axis may be oriented.

In the bottom end portion of the tubular member 61 the optico-electric system comprises a lens 65; the dimensioning of the various components of the apparatus is such as to place this lens at a distance from the surface S somewhat greater than the focal length of the lens. At the top of the tubular member 61 the system comprises a tube 68 telescoped around and extending upwardly from that member, secured to it by a clamping screw 67 passing through a vertically elongated aperture in the tube 68, and having its upper end closed by a relatively thick cap member 69. The system finally comprises photoelectric means, secured in the cap member 69, next described and designated generally as 70.

For the scanning of a line indicium the photoelectric means 70 comprises two photoelectric devices 71 and 72. While in connection with some aspects of the invention these may be of any form whose electrical state is varied by incident light, it is strongly preferred that they be light-modulated resistors; the description will therefore be presented in terms of such resistors, it being understood that there are not thereby intended limitations not expressed in the claims.

A typical light-sensitive resistor is a device whose resistance decreases to a degree dependent on the light incident on a light-sensitive area of the resistor, which area may for example be a surface formed of such material as cadmium sulfide or cadmium selenide; mechanically the resistor may be in the form of a small cylinder in one end of which the light-sensitive area is disposed. The two photoelectric devices 71 and 72 may comprise two such resistors, preferably peripherally contiguous to each other, with their parallel axes lying in the plane of FIGURE 7 and equally displaced in respective directions from the axis of the optico-electric system (i.e. of tubular member 61). Optically these resistors may present toward the lens coplanar disc surfaces on which respective central rectangles 71a and 72a from light-sensitive areas; each of these rectangles, which along their major dimensions are aligned with each other, may typically extend along that dimension for about three-fourths of the resistor diameter.

By the lens 65 there will be projected onto the plane of the light-sensitive areas 71a and 72a an image of the indicium which appears on the surface S. The lengthwise direction of the image is such as to render the line

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between the centers of the areas, and thus their mutually aligned major dimensions, transverse to the image; FIGURE 8 illustrates as I a shaded strip representing that image for the case of the line indicium L of FIGURE 1. Positioning of the plane of 71a and 72a to result in the desirable accurate focussing of the image at that plane is provided for by the limited axial movability of the tube 68 relative to the tubular member 61. Advantageously, the width of the line indicium and the degree of magnification of the image relative to the line are so chosen that the width of the image will be of the same order of magnitude as the major dimension of either of the areas 71a and 72a and preferably is substantially the same. As will hereinafter appear, the normal lateral relationship of the image relative to those rectangles is one of equal partial overlaps; in view of the typical dimensioning mentioned above, the extent to which the image will marginally overlies each of the areas may be of the order of one-third of the area (as for example about one fourth of the whole cell diameter).

Illumination of the portion of the indicium of which the image is projected by the lens 65 may be provided in any convenient manner. By way of example FIGURE 3 illustrates an electric bulb 5 contained in a suitable housing 7; the housing may be carried at the lower end of an adjustable goose-neck 8 secured at its upper end to the platform, and may be provided with a suitable condensing lens 6 for the concentration of a substantial portion of its light output on the surface S underneath the lower end of the optico-electric system.

In order to make electrical connections from stationary circuitry to the terminals of the light sensitive resistors, which are contained in the angularly movable barrel 50, that barrel may be provided at its top with a cylindrical upward extension 49 of insulating material in the surface of which (see FIGURE 3) are inset a plurality of parallel spaced slip rings 77 respectively connected to the cell terminals. Electrical connections to these slip rings and thus to the resistor terminals may be made by spaced spring contact fingers 78 which are secured to a suitable insulating block 79 on top of the platform 12 and from that block extend into contact with the respective slip rings.

Attention may now be directed to the electric circuitry by which the light-sensitive resistors 71 and 72 control the servo motor 45, reference being had to FIGURE 9. These resistors 71 and 72 are connected in a balanceable electric circuit designated generally as 80, through respective pairs 81 and 82 of switch blades whose function is hereinafter described. The circuit 80 may include in closed serial arrangement the secondary of a transformer 85 (whose primary is supplied with A.C., for example of 60 cycles), the resistor 71, the full resistance of a balancing potentiometer 86, and the resistor 72. Between the movable contact of the potentiometer 86 and a center tap on the transformer secondary there is connected the full resistance of an output potentiometer 87, thus creating two sub-circuits one of which comprises the lefthand half of the transformer secondary, the resistor 71, the lefthand portion of potentiometer 86 and the full resistance of potentiometer 87, and the other of which comprises the righthand half of the secondary, the resistor 72, the righthand portion of potentiometer 86 and the full resistance of potentiometer 87. Alternating currents flow simultaneously and in all half cycles through the two sub-circuits; those currents are of course in opposition to each other in the common portion constituted by the potentiometer 87, and when they are equal the voltage drop across that potentiometer is of course zero.

A regulable fraction of any A.C. voltage appearing across that potentiometer is applied, through conductor 88 leading from one potentiometer to ground and conductor 89 leading from the movable contact of that potentiometer, to the input of a transistor amplifier designated generally as 90. The transistor amplifier may comprise three stages

91, 92 and 93 respectively, of which the first is direct-coupled to the second and the second is transformer-coupled to the third, which is a push-pull stage.

For the amplifier 90 there is provided a D.C. power supply 100, comprising a transformer 101 having the bridge rectifier 102 connected to its main secondary and the filter 103 connected to the output of the rectifier. The conductor 104 carries the output of the power supply to the second and third stages of the amplifier; because of the sensitivity of the direct-coupled arrangement to the voltages applied to the first stage, the latter are derived in the amplifier from the conductor-104 voltage through a stabilizing network including series resistor 94 and shunt zener diodes 95 (the base-to-emitter bias being provided by division of the stabilized voltage through appropriate high-valued resistors 96 and 97). The primary of the power-supply transformer 101 is shown connected (preferably through switching means performing wholly auxiliary functions and hereinafter referred to) to a source of alternating current; this is preferably of stabilized voltage. This transformer may have an additional secondary across which the illuminating bulb 5 may be connected.

The A.C. output from the push-pull stage 93, which constitutes the output of the amplifier, is supplied directly to the control phase or winding 112 of the servo motor 110 (a center-tap on that winding being the point of connection of the bias conductor 104 to the third stage); across the winding 112 there is connected a capacitor 99 which resonates with the effective inductance of that winding at the frequency of the A.C. supply. The servo motor 110 will of course also have a reference phase or winding 111, to which there is applied alternating current of phase shifted, as by an appropriate series capacitor 113, by substantially 90° from the phase of that supplied to the balanceable circuit 80.

A regulable mechanico-electric negative or stabilizing feedback is provided from the shaft of the servo motor 110 to the input of the amplifier 90, by an A.C. tachometer generator 115 co-shafted with the servo motor. This tachometer generator has its reference phase or winding 116 supplied with alternating current of the same phase as that supplied to the balanceable circuit 80; it has its output phase or winding 117 connected across a potentiometer 118 of which a regulable portion is serially interposed in the conductor 88 so that the voltage across that portion becomes algebraically added to the output voltage from the circuit 80. Mechanically the tachometer generator 115 appears in FIGURE 3 at the top of the servo motor 110.

Of the remaining components schematically shown in FIGURE 9, it is sufficient at this juncture to mention only the driving motor 40, previously referred to in the mechanical description. This may be of the well-known so-called Lee type, whose speed is maintained approximately constant by serially arranged governor-operated contacts 39. It has been shown as connected (preferably through switching means performing wholly auxiliary functions and hereinafter referred to) across an A.C. supply, for example of 60 cycles.

Let it be assumed that the carriage is in the position illustrated in FIGURES 1, 2 and 3 and moving along the line indicium L in a leftward direction, that the axis of the optico-electric system intersects the indicium midway between the edges of the latter, and that the lens 65 is therefore projecting onto the plane of the sensitive areas 71a and 72a the dark image I of the indicium in the laterally centered position illustrated in FIGURE 8; under these conditions the fractions of the respective areas 71a and 72a covered by the dark image are equal (and the lighted fractions of those areas are equal and therefore the resistances of 71 and 72 at least nearly equal). The balancing potentiometer 86 will previously have been adjusted so that under these conditions there will be zero voltage drop across the output potentiometer

87 and therefore no output from the amplifier and no rotation of the servo motor 110.

This state of affairs will continue as the carriage movement continues so long as there is no departure of that axis from the center of the line indicium. If and when a departure begins, one of the areas 71a and 72a will become slightly less covered and the other slightly more covered by the image; the resistance of one of the resistors 71 and 72 will decrease and that of the other will increase; an A.C. voltage of magnitude depending on the degree of the departure, and of one or the opposite phase according to the direction of the departure, will appear across the output potentiometer 87 and will be applied to the input of the amplifier 90; an amplified alternating current corresponding in amplitude and in directivity (i.e., phase) to that voltage will be supplied by the amplifier to the servo motor; and the servo motor will rotate, with an acceleration and in a direction respectively corresponding to that amplitude and that directivity, steering the moving carriage (through gear 22) so as to bring the axis of the optico-electric system back to the lateral center of the indicium. Thus each incipient departure occasions an action which annuls that departure; the net result is that the movement of the carriage takes place with the axis of the optico-electric system strongly constrained to remain aligned with the lateral center of the line indicium, therefore takes place in a path corresponding extremely closely with that indicium—whatever the corners, curves or other deviations from rectilinearity may characterize that indicium.

It will also be appreciated that concomitantly with the steering, or control of the direction of propulsion, of the carriage there will be exerted (through gear 52) a control of the angular position of the barrel 50 and thus of the pair of light-modulated resistors 71 and 72 (considered as a pair), the result of which is to maintain the mutually aligned major dimensions of the areas 71a and 72a at right angles to the indicium L and its image I so that relative thereto those areas remain in the orientation which makes possible the continuing action described in the preceding paragraph.

For stability of behaviour of the apparatus it is important that the point of intersection of the axis of the optico-electric system with the line indicium (and thus with the surface S) be very slightly displaced forwardly (i.e., in the direction of carriage movement) from the point at which the surface S is intersected by the vertical axis of rotation of the barrel 50. It is in order to provide for this displacement—to which the term "lead" is frequently applied—that the optico-electric system 60 is pivoted on the studs 53. Thus in FIGURE 6 it will be seen that the axis A of that system has (by the adjusting screws 59) been rocked away from a vertical plane normal to the indicium so as to intersect the surface S slightly (in the illustration, somewhat exaggerated) in advance of the vertical axis V about which the barrel 50 is angularly movable.

When the ultimate function to be performed is the guidance, over work such as W, of a tool such as the cutting torch T of FIGURE 1, the path P cut by that tool may be a path of finite width, to which width the term "kerf" is frequently applied. If the axis A be vertical as seen looking along the indicium (i.e., as seen in FIGURE 7), it will be the center line—and not either edge—of the path P which will correspond to the indicium (strictly, to the lateral center line of the indicium), and a piece separated from the work by a closed path P (such as piece Z in FIGURE 1) will all around its contour be marginally smaller than the area defined by the original indicium L by half the kerf. It is in order to permit compensation for the half-kerf that the tube 51 is pivoted on the studs 55, about which its angular movement will rock the axis A of the optico-electric system away from the vertical plane containing the indicium. Thus in FIGURE 7 the axis A has (by adjusting screw 56) been

rocked so as to intersect the surface S at a point spaced away from the intersection of the axis V with that surface—in the direction which is inward of the closed indicium L—by half the kerf cut by the tool being guided by the system. The result is that the carriage movement actually takes place in a path marginally larger than the closed indicium L by half the kerf, and the piece Z separated from the work will just correspond in size to the closed indicium.

The line tracer as thus described is one of relatively great simplicity and dependability. The use of mutually fixed unpolarized light-modulated resistors simultaneously sensitive and simultaneously traversed by alternating currents which are simply balanced, and the facile amplification of the resulting A.C. net or difference to create the energizing power for the servo motor, circumvents a large number of problems and of requirements for nice adjustments which are involved when true photoelectric cells, photo-diodes or -transistors or other polarized devices are used, or when the two are rendered alternately sensitive, or when conversion from A.C. to D.C. or vice versa is called for in the apparatus, and the like. Lead and kerf adjustments, moreover, are provided in exceptionally simple and dependable form.

A further feature may be commented on in greater detail than has been done above. This is the use, in the light-modulated resistors 71 and 72 respectively, of definitely elongated light-sensitive areas (71a and 72a) aligned with each other in the direction transverse of the image. The elongation goes hand in hand with restriction of the dimension in the direction longitudinal of the image—which dimension it is preferred to restrict to a minor fraction, typically of the order of a fifth to a quarter, of the transverse or major dimension (or of the image width, which as above-mentioned may be of the same order as that major dimension). First it permits, in a circularly shaped device, a maximization of the other or transverse dimension; further, it increases the definition of the scanning, in particular at corners or other divergences from rectilinearity of the indicium; still further, it appears to increase, even beyond the degree explainable by better definition, and especially at moderate carriage-travel speeds, the fidelity with which the apparatus traces through such divergences.

The accomplishment of the automatic steering of the carriage above described requires that any lateral displacement of the image away from normal relationship to the areas 71a and 72a (or in other words of the axis of the optico-electric system from the lateral center of the line indicium) shall stop short of the degree at which both of those areas become wholly light, for at and beyond that degree there will be no or essentially no output from the bridge and the carriage will move in an arbitrarily directed straight or essentially straight line—the tool being guided by the carriage meanwhile operating on wholly unintended parts of the work. It is therefore highly desirable that if through any maloperation that degree is approached, the propulsion of the carriage be forthwith stopped. To accomplish such stoppage there may be inserted electrically in series with the driving motor 40 the contacts 122 of a relay 120 (of the so-called normally-open-contact variety) of which the coil 121 is energized to hold those contacts closed only so long as any displacement of the image remains of substantially less than that degree.

Such energization of the coil 121 may be provided under the control of a third photoelectric device 73 included in the photoelectric means 70, the device 73 preferably being a light-modulated resistor of form and nature similar to the light modulated resistors 71 and 72 and, like those resistors, preferably having an elongated light-sensitive area 73a. Of this light-sensitive area the major dimension may, like those of the areas 71a and 72a, be transverse to the image, but it will be laterally intermediate and preferably centered between the lateral positions of those areas; longitudinally of the image it will be displaced from

the line joining the centers of the areas 71a and 72a, preferably sufficiently to avoid interference by the device 73 with the contiguity of the devices 71 and 72, and preferably in the direction mechanically opposite to that of travel of the carriage—which direction will be recognized as the direction from which the image in effect moves past the photoelectric means. Typically the resistor 73 will be positioned in peripheral tangency to each of the resistors 71 and 72, the three being for example strapped together as by band 74 and secured as a unit within a suitable aperture in the cap member 69. Because of its laterally intermediate position the area 73a will be overlain and therefore substantially darkened by the image so long as the axis of the optico-electric system occupies its normal lateral position of intersection with the lateral center of the line indicium; as the carriage is moved in any manner which substantially shifts that axis away from that lateral center, however, the image will be moved and will progressively uncover and thus lighten the area 73a. With the suggested typical dimensioning the area 73a will for example be normally just covered by the image, but will be two-thirds uncovered when the image has been laterally displaced sufficiently to exert its maximum darkening effect on either of the areas 71 and 72.

Electrically the light-modulated resistor 73 may be connected, through a pair of switch blades 83, as the lower part of a D.C. voltage divider formed by it and a resistor 129 whose upper terminal is connected to the conductor 104 which carries the positive output potential of the power supply 100. Thus the upper or non-grounded terminal of the light-modulated resistor 73 will be positive with respect to ground by a potential which may be considered to have a normal value when the axis of the optico-electric system is laterally centered on the line indicium and the area 73a therefore substantially darkened and the resistance of 73 therefore a maximum, but which will progressively decrease from that normal as that axis is substantially decentered laterally and the area 73a therefore progressively more and more illuminated.

The positive potential of the upper terminal of resistor 73 may be impressed upon the input of a D.C. transistor amplifier 130 to the output of which the relay coil 121 is connected. This amplifier, to which electrode power may be supplied from the conductor 104, may typically comprise two direct-coupled stages 131 and 132 in which the emitter of the first is directly connected to the base of the second. A zener diode 135 connected between the emitter of the second stage and ground establishes a maximum for the bias on the second stage, while a simple diode 134 between the amplifier input and the second-stage emitter prevents the value of the positive input potential from falling very much below the value of the second-stage bias (which were it to occur might apply damaging reverse voltages across the base-to-emitter paths of the transistors). A capacitor 133 in the amplifier between its input and ground is desirable to effect a minute delay of each change of its input potential; a diode 139 in the amplifier across its output may serve to divert from the coil 121 abrupt transients which may nevertheless be developed in the output.

The circuit constants are so fixed that the positive input potential—i.e., the D.C. potential of the upper terminal of the light-sensitive resistor 73—while it has the normal value mentioned in the second preceding paragraph will be appreciably in excess of the maximum second-stage bias, under which condition the output current (i.e., collector current of the second stage) will be ample to hold the relay contacts 122 closed. As that input potential is reduced as discussed at the end of that paragraph, however, the output current will be progressively reduced and during this process will reach a critical value just insufficient to maintain the contacts 122 closed, whereupon those contacts will open and stop the operation of the driving motor 40. Adjustment of the value of resistor 129 will predetermine the normal value of the input potential, and with it

the degree of displacement—of the axis of the optico-electric system from the lateral center of the line, and of the image from normal relationship to the light-sensitive areas 71a and 72a—at which this stoppage will occur.

The stopping of the propulsion of the carriage is inherently a signal to the operator of the apparatus that the axis of the optico-electric system has substantially digressed from the lateral center of the line indicium. (Such a signal is also provided by the operation of the relay 120, which may be observed audibly or visually or by a pilot light, not shown, controlled by appropriate additional contacts on the relay.) He may then by inspection determine the direction and degree of the digression, and may by hand steer the carriage back to a proper relationship of the axis to the indicium; the driving motor may be called on to provide propulsion during such hand steering, notwithstanding the open condition of contacts 122, by the operator's temporarily closing an openly-biased "jog" switch 123 connected across those contacts.

For various other and less transient purposes it may be desirable on occasion to effect propulsion of the carriage without automatic steering (i.e., during which steering will be accomplished manually by the operator), and to accommodate this other switching means may be provided. These switching means may for example comprise a normally closed switch 124 interposed in the circuit of the primary of the transformer 101 and a normally open switch 125 connected across the contacts 122, the switches 124 and 125 being mechanically interconnected so that they may be thrown simultaneously to their respectively opposite conditions. It will be understood that when they are thus thrown the power supply 100 (and illuminating lamp 5) will be deenergized, in turn deenergizing the amplifiers 90 and 130 and thus rendering inoperative the automatic steering and off-line stopping functions, while the driving motor 40 will be energized to propel the carriage.

The tracer as thus far described is one for the tracing of a line indicium. Over and beyond aspects of the invention involved in the disclosure up to this point, other aspects are directed to the facile conversion of the tracer to one for the tracing of an edge indicium. Such an indicium—and its image, which as in the case of the line will be projected by the lens 65—constitutes simply the demarcation between side-by-side light and dark areas.

For the tracing of an edge indicium there is sufficient the use of a single photoelectric device, preferably again a light-modulated resistor and again having an elongated light-sensitive area with its major dimension disposed transversely to the indicium and the image; in contrast to either one of the light-sensitive areas 71a and 72a in line tracing, however, the light-sensitive area of this single device will normally extend from within the area on one side of the image into the area on the other side. It would be possible to use for this single device one of the light-modulated resistors 71 and 72; since each of these resistors is wholly disposed on one or the other side of the lateral center of the line-tracing image, however, the use of either for edge tracing would necessitate, in a change of use from line to edge tracing or vice versa, a significant readjustment of the tube 51 about the pivots 55, destroying the previous adjustment for kerf and necessitating the making of a new one.

An off-indicium stopping function is not necessary in connection with edge tracing. (This results from the fact that the wholly light or wholly dark state of the area 73a caused by the off-line condition will result in a maximum output from the bridge in one or the other phase, in turn in a rapid rotation of the servomotor, and in turn in the movement of the carriage in a minute circle—the tool being guided by the carriage meanwhile standing essentially stationary.) It follows that the use of the light-modulated resistor 73 for off-indicium stopping is not required in edge tracing. Advantage is taken of this fact, and in edge tracing the resistor 73 is called into use as the

single required photoelectric device. It is for this reason that the resistor 73 has been connected to the off-line amplifier 130 through the pair of switch blades 83; for edge tracing that pair of blades may be thrown to disconnect that resistor from that amplifier and to substitute it, in the balanceable circuit 80, for the light-modulated resistor 71 which by simultaneous throwing of the pair of switch blades 81 may be disconnected from the circuit. Also simultaneously the pair of switch blades 82 may be thrown to disconnect from the circuit the light-modulated resistor 72 and to substitute therefor an adjustable resistor 126, the three pairs of switch blades 81, 82 and 83 being mechanically interlinked for such simultaneous action.

In initially adjusting the apparatus for edge tracing the carriage may be positioned longitudinally of an edge indicium to place the optico-electric system (unreoriented from its line-tracing orientation) over a straight segment of that indicium, and may be laterally positioned so that the major dimension of the light-sensitive area 73a is accurately bisected by the image of the indicium—a state of affairs illustrated in FIGURE 10, in which that image is designated as J. Under these conditions there will intersect the straight segment of the indicium not only the axis A of the optico-electric system but also the line B (see FIGURE 6) along which the lens 65 projects from the surface S onto the very center of the light-sensitive area 73a—and it will be understood that it is now the line B rather than the axis A which is of significance in the operation of the apparatus. Now with the switch blades 81, 82 and 83 thrown to their edge-tracing positions, the resistor 126 will be adjusted to that value which, without readjustment of the balancing potentiometer 86 from its line-tracing setting, will cause the balanceable circuit 80 to develop zero output across potentiometer 87.

Let it now be assumed that the carriage is moving along the edge indicium first without departure of the line B from intersection with the indicium; the light-sensitive area 73a will remain bisected by the image J and will thus be half light and half dark, and there will continue to be no output from the balanceable circuit and no rotation of the servo motor 110. If and when a departure begins, the area 73a will become slightly more or slightly less than half light; the resistance of the resistor 73 will slightly decrease or slightly increase; and an A.C. voltage of magnitude depending on the degree of the departure, and of one or the opposite phase according to the direction of the departure, will appear across the output potentiometer 87. This voltage will be recognized as entirely analogous to the voltage appearing across that potentiometer in the case of the tracing of a line indicium—and its use and effect are of course the same, excepting only that it will now be the line of projection B which will be brought back to the edge indicium (rather than the axis A being brought back to the lateral center of the line indicium) to steer the carriage in a path corresponding extremely closely with the indicium. The concomitant control of the angular position of barrel 50 of course still takes place, its important function now being to maintain the major dimension of the single light-sensitive area 73a at right angles to the indicium and its image J.

For stability of behaviour, lead—now the forward displacement of the point of intersection of the line B with the surface S from the point of intersection of the vertical axis V with that surface—remains important; the magnitude of lead in edge tracing, however, is preferably greater than that of the lead in line tracing. The requisite differentiation will be observed (see FIGURE 6) to be inherently provided, without any readjustments of the apparatus, by the above-described arrangement according to the invention, wherein the displacement of the center of the light-sensitive area 73a from the line joining the centers of the areas 71a and 72a is in the direction mechanically opposite to that of travel of the carriage (and

thus in the direction from which the image in effect travels past the photoelectric means).

It will be understood that in the view presented by FIGURE 7 the line B coincides with the axis A of the optico-electric system and therefore does not appear separately. It will further be understood that in edge tracing the displacement of the line B from the vertical plane containing the indicium performs precisely the same function, of adjustment of half-kerf, that the similar displacement of the axis A performs in line tracing. It is further to be noted that as a result of the dispositions of the light-sensitive areas according to the invention the half-kerf adjustment, which is peculiar to a tool being guided and not to the indicium, remains undisturbed by a shift of the indicium from line to edge or vice versa.

The invention has been disclosed as used in a tracer which may trace an indicium of any configuration, in which the carriage is steered by angular control, and which provides not only for steering of the carriage but also for control of the angular position of the photoelectric means within the carriage. Various aspects of the invention, however, may be useful in connection with a tracer which is to be used only for the tracing of a substantially rectilinear indicium, with a tracer which steers by lateral movement of the carriage, or with a tracer which (for example, by reason of substantial rectilinearity of the indicium) does not provide for control of the angular position of the photoelectric means within the carriage. An example of such an alternative tracer might be one for the guidance of a welding head along an elongated seam relative to which the carriage is steered by lateral movement.

The description has referred to a line in the form of a narrow strip of one luminosity, typically low, physically present on a background of a different luminosity, typically high; it will be understood, however, that the line may be a virtual one only, created for example by an elongated shadow, so long as its image as projected by the lens appears to the photoelectric means as similar to the projected image of a real line. Again, while there has been disclosed the preferred supply of A.C. to the bridge together with an A.C. amplifier 90 and an A.C. servo motor 110 and an A.C. tachometer generator 115, it will be understood that many of the features of the invention will be useful with a D.C. supply to the bridge, appropriate modifications then being made in the amplifier-and-motor-and-generator part of the apparatus.

While the invention has been disclosed in terms of a particular embodiment, it will be understood that there are thereby intended no unnecessary limitations. Modifications in many respects will be suggested by the disclosure to those skilled in the art, and such modifications will not necessarily constitute departures from the spirit of the invention or from its scope, which the following claims undertake to define.

I claim:

1. In a line tracer, the combination of a carriage propellable over a surface bearing a line to be traced but restrained against rotation parallel to that surface; an optico-electric system, carried by the carriage, comprising means for projecting an image of a longitudinal segment of the line and a pair of mutually fixed photoelectric devices having respective elongated light-sensitive areas aligned with each other transversely to, and each partially overlain by a respective margin of, the image, at least said pair of photoelectric devices being angularly movable within the carriage about an axis normal to said surface; balanceable electric-circuit means, including an electric current source connected to and from which respective currents are passed through said photoelectric devices for modulation by the light incident on their respective said areas, for producing an electric output of directivity and magnitude respectively corresponding to the direction and degree of displacement of the image

from a predetermined lateral relationship to said areas; and servo-motor means responsive to said output for steering the carriage and concomitantly controlling the angular position of said pair of photoelectric devices about said axis.

2. The subject matter claimed in claim 1, wherein said photoelectric devices are light-modulated resistors.

3. The subject matter claimed in claim 1, wherein said light-sensitive areas extend along the image only for a distance which is a minor fraction of the width of said image.

4. In a line tracer, the combination of a carriage propellable over a surface bearing a line to be traced but restrained against rotation parallel to that surface; an optical-electric system, carried by the carriage, comprising means for projecting an image of a longitudinal segment of the line and a pair of mutually fixed unpolarized photoelectric devices having respective light-sensitive areas the line between whose centers is transverse to, and each of which is partially overlain by a respective margin of, the image, at least said pair of photoelectric devices being angularly movable within the carriage about an axis normal to said surface; balanceable electric circuit means, including an electric alternating-current source connected to and from which respective alternating currents are passed in all half-cycles through said photoelectric devices for modulation by the light incident on their respective said areas, for producing an A.C. output of directivity and magnitude respectively corresponding to the direction and degree of displacement of the image from a predetermined lateral relationship to said areas; and servo-motor means responsive to said output for steering the carriage and concomitantly controlling the angular position of said pair of photoelectric devices about said axis.

5. The subject matter claimed in claim 4 wherein said photoelectric devices are light-modulated resistors.

6. In a line tracer, the combination of a carriage propellable over a surface bearing a line to be traced but restrained against rotation parallel to that surface; an optico-electric system, carried by the carriage, comprising means for projecting an image of a longitudinal segment of the line and a pair of mutually fixed light-modulated resistors having respective elongated light-sensitive areas aligned with each other transversely to, and each partially overlain by a respective margin of, the image, at least said pair of light-modulated resistors being angularly movable within the carriage about an axis normal to said surface; balanceable electric-circuit means, including an electric alternating-current source connected to and from which respective alternating currents are passed in all half-cycles through said light-modulated resistors for modulation by the light incident on their respective said areas, for producing an A.C. output of directivity and magnitude respectively corresponding to the direction and degree of displacement of the image from a predetermined lateral relationship to said areas; an A.C. amplifier to the input of which the output of said balanceable circuit is supplied; and servo-motor means responsive to the output of said amplifier for steering the carriage and concomitantly controlling the angular position of said pair of light-modulated resistors about said axis.

7. The subject matter claimed in claim 6, wherein said light-sensitive areas extend along the image only for a distance which is a minor fraction of the width of said image.

8. In an edge tracer, the combination of a carriage propellable over a surface bearing dark and light areas demarcated by an edge but restrained against rotation parallel to that surface; an optico-electric system, carried by the carriage, comprising means for projecting an image of a longitudinal segment of the edge and a photoelectric device having an elongated light-sensitive area transverse to and crossed by the image, at least said photoelectric device being angularly movable within the carriage about an axis normal to said surface; a resistor; balanceable

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electric-circuit means, including an electric current source connected to said photoelectric device and said resistor and from which a current is passed through said photoelectric device for modulation by the light incident on its said area and another current is passed through said resistor, for producing an electric output of directivity and magnitude respectively corresponding to the direction and degree of displacement of the image from a predetermined lateral relationship to said area; and servo-motor means responsive to said output for steering the carriage and concomitantly controlling the angular position of said photo-electric device about said axis.

9. The subject matter claimed in claim 8, wherein said photoelectric device is a light-modulated resistor.

10. A line tracer comprising in combination a carriage advanceable along a line to be traced; photoelectric means, carried by the carriage, comprising a pair of mutually fixed photoelectric devices having respective light-sensitive areas and means for projecting an image of a longitudinal segment of the line onto the photoelectric means in a normal lateral relationship to said areas wherein a respective margin of the image partially overlies each of said areas; means controlled by said devices for steering the carriage; a third photo-electric device comprised in said photoelectric means and having a light-sensitive area laterally positioned between the lateral positions of said first mentioned areas so as to be normally overlain by the image; and means controlled by said third device for stopping the advance of the carriage when the image is laterally displaced in predetermined degree from said normal relationship to said first-mentioned areas.

11. The subject matter claimed in claim 10, wherein said light-sensitive area of said third device is displaced, from said areas of said pair of devices, in the direction from which the image is effectively moved past the photoelectric means by the advance of the carriage.

12. Apparatus for the tracing of an elongated indicium which may alternatively be a line and an edge, comprising in combination a carriage advanceable along the indicium; phototelectric means, carried by the carriage, comprising a pair of mutually fixed photoelectric devices

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having respective light-sensitive areas, a third photoelectric device having a light-sensitive area, and means for projecting an image of a longitudinal segment of the indicium onto the photoelectric means so that a respective margin of the image of such segment of a line indicium partially overlies each of said areas of said pair of devices and the image of such segment of an edge indicium crosses said area of said third device; and means, electrically interposed between the photoelectric means and said steering means, selectively adjustable to subject said steering means alternatively to control by said pair of devices for line tracing and to control by said third device for edge tracing.

13. The subject matter claimed in claim 12, wherein said light-sensitive area of said third device is displaced, from said areas of said pair of devices, in the direction from which the image is effectively moved past the photoelectric means by the advance of the carriage.

14. The subject matter claimed in claim 12, wherein the lateral position of said light-sensitive area of said third device is intermediate the lateral positions of said light-sensitive areas of said pair of devices.

15. The subject matter claimed in claim 12 further including means for stopping the advance of the carriage and means, connected with said selectively adjustable means, for subjecting said stopping means to control by said third device while said steering means is subjected to control by said pair of devices.

16. The subject matter claimed in claim 12, further including means for signalling an off-line condition and means, connected with said selectively adjustable means, for subjecting said signalling means to control by said third device while said steering means is subjected to control by said pair of devices.

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