March 3, 1970 G. R. TURBETT 3,499,155

PHOTOELECTRIC KERF AND LEAD COMPENSATOR HAVING TWO CONCENTRIC PIVOTABLY MOUNTED HOUSINGS FOR COMPENSATION IN TWO DIRECTIONS

Original Filed Feb. 7, 1964 2 Sheets-Sheet 1

FIG. 2

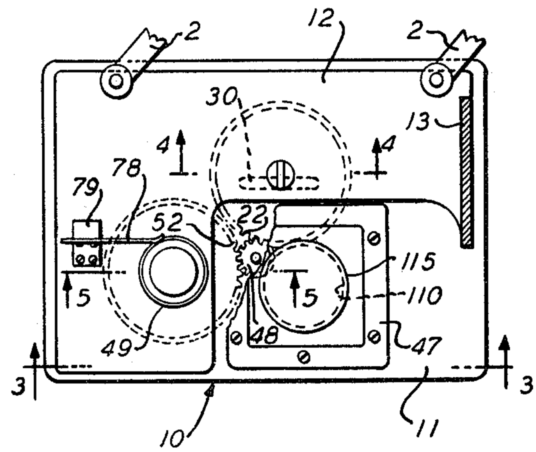

FIG. 1

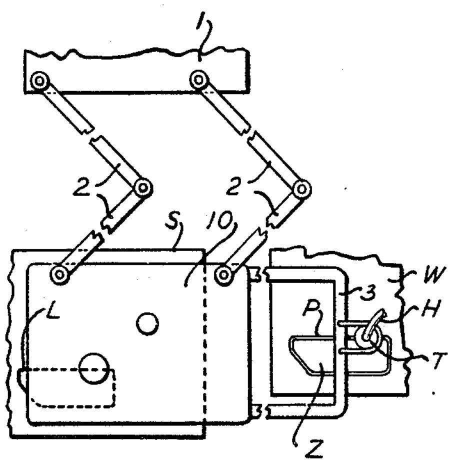

FIG. 3

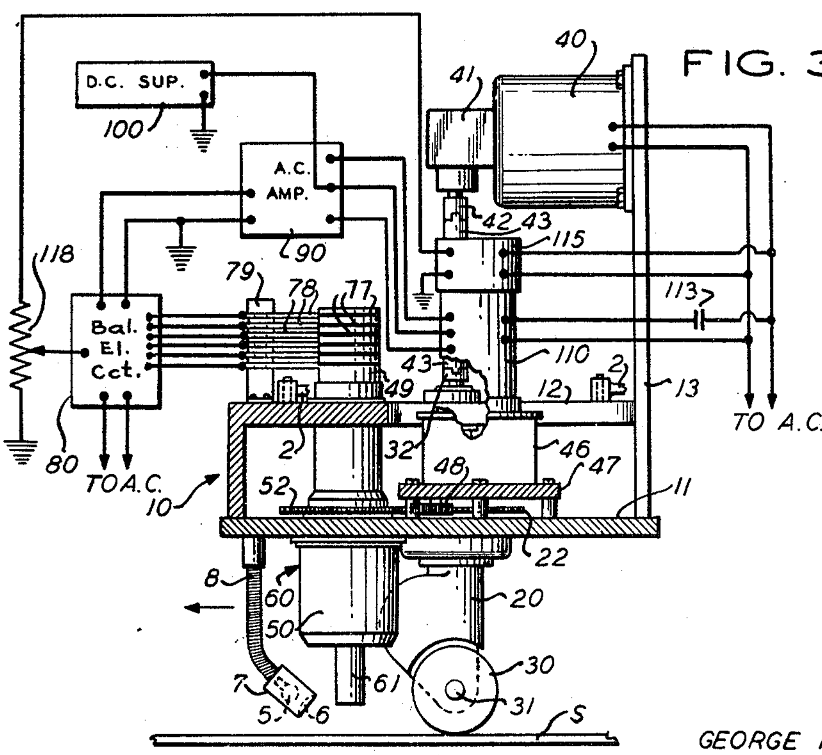

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FIG. 5

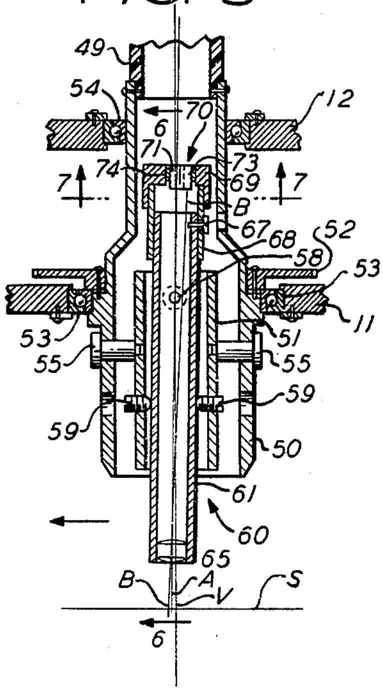


FIG. 6

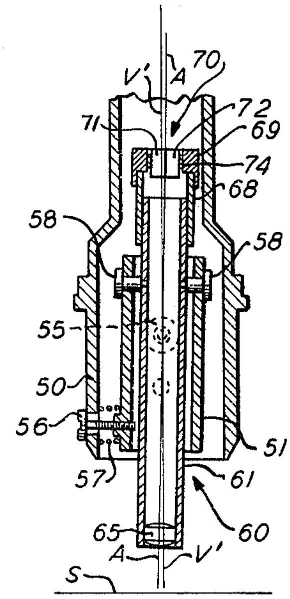


FIG. 7

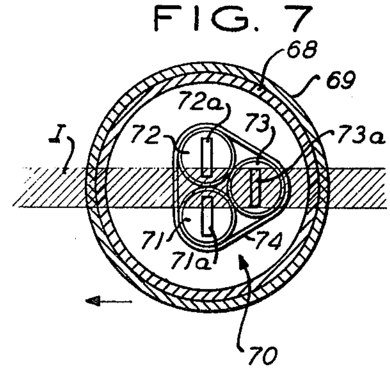
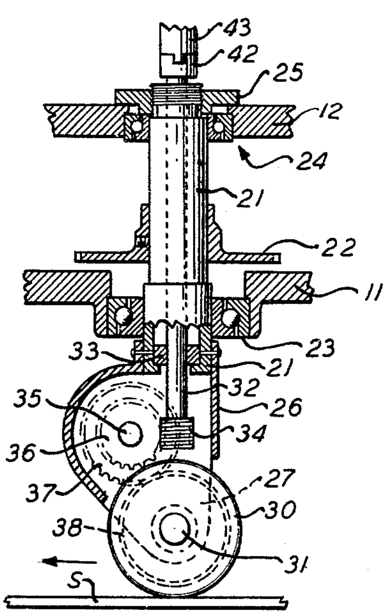


FIG. 4



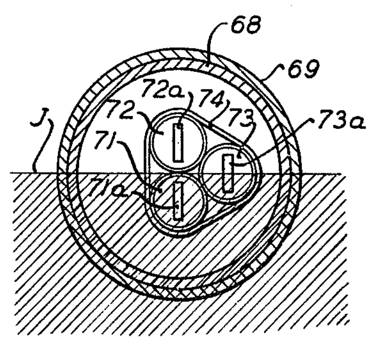


FIG. 8

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PHOTOELECTRIC KERF AND LEAD COMPENSATOR HAVING TWO CONCENTRIC PIVOTABLY MOUNTED HOUSINGS FOR COMPENSATION IN TWO DIRECTIONS

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Continuation of application Ser. No. 343,327, Feb. 7, 1964. This application Aug. 29, 1968, Ser. No. 756,331
Int. Cl. G05b *1/00*
U.S. Cl. 250—202 6 Claims

ABSTRACT OF THE DISCLOSURE

A kerf and lead compensator for a line-following device in which a lens and photocell are mounted in an elongated housing which in turn is pivotably mounted in an intermediate support member for pivoting in a first plane. The intermediate support member is pivotably mounted in a main support member for pivoting in a second plane, thus permitting compensation in two directions.

This application is a continuation of Ser. No. 343,327, filed Feb. 7, 1964.

This invention relates to a Tracer, and more particularly to one photoelectrically controlled by an indicium—e.g. either a finite-width line or an infintesimal-width edge—which it is to trace. The invention is especially concerned with an improved optico-electric system in such a tracer.

In brief, the invention comprises the combination of an optico-electric system, carried by the carriage, comprising the photoelectric means and the lens, between that means and the indicium-bearing surface, for projecting onto that means an image of a longitudinal segment of the indicium, that system being angularly movable within the carriage about an angle normal to that surface; electric means, controlled by the photoelectric means, for determining the direction of propulsion of the carriage and controlling the angular position of the photoelectric means about that axis; and means for adjustably inclining the optico-electric system as a unit relative to a normal to the surface. The inclining may be in a plane transverse to the surface and extending along the indicium (for lead), or in a plane transverse both to the surface and to the indicium (for kerf compensation), or in each of those planes. It is in the optico-electric system that there may be incorporated means for altering the distance between the photoelectric means and the lens to provide for sharp focusing of the image on the photoelectric means. The optico-electric system may comprise a generally tubular member, with which the lens is typically coaxial, in which both the photoelectric means and the lens are mounted; a set of gimbals may be used for mounting that member in the carriage, thereby providing for the adjustability previously mentioned. For the tracing of a line indicium the photoelectric means may comprise a pair of photoelectric devices having respective light-sensitive areas aligned with each other transversely to, and each partially overlain by, the image; for the tracing of an edge indicium the photoelectric means may comprise a single photoelectric device having a light-sensitive area crossed by the image.

The invention has especial, though not in all aspects necessarily unique, utility in a tracer in which a carriage is propellable over a surface bearing an indicium to be traced but is restrained against rotation parallel to that surface; in which there are carried by the carriage both photoelectric means and a lens for projecting onto the photoelectric means a well-defined image of a longitudinal segment of the indicium, the photoelectric means being angularly movable within the carriage about an axis normal to the indicium-bearing surface; in which there is controlled by the photoelectric means an electric circuit which produces an electric output of directivity (i.e. polarity if D.C., phase if A.C.) and magnitude respectively corresponding to the direction and degree of displacement of the image from a predetermined lateral relationship to the photoelectric means; and in which that electric output controls means which determine the direction of propulsion of the carirage and which control the angular position of the photoelectric means about the abovementioned axis. By way of non-limitative example the tracer may be one of the type disclosed in U.S. Patent No. 3,135,904 of Rawlins E. Purkhiser, assigned to the assignee of the present invention, filed Jan. 15, 1962; in this type of tracer there is employed a single propelling motor which turns a carriage-propelling wheel, and the determination of the direction of propulsion of the carriage is effected by a true steering control of that wheel.

Whether or not of the particular type last mentioned, the typical tracer contemplated by the invention may be considered as one in which the dynamic carriage position along the indicium-bearing surface is influenced inter alia by the interrelationship, taken along the indicium-bearing surface, between a longitudinal segment of the indicium and the image of that segment projected by the lens onto the photoelectric means—by way of more specific example, between the point in the indicium which is longitudinally central of that segment and is also transversely central of the segment (or simply on the segment if that be of infinitesimal width), and the corresponding point in the image. As a fundamental or reference relationship there is customary one in which both the indicium point and the image point just mentioned lie on the abovementioned axis (normal to the indicium-bearing surface) about which the photoelectric means is angularly movable.

It is, however, well understood that to provide for stability of behavior of a tracer of the general type above described it is ordinarily important that the indicium point just mentioned be displaced from that axis (without a corresponding displacement of the image point) very slightly forwardly (i.e. in the direction of carriage movement)—this displacement being commonly referred to as "lead." It is also well understood that if the ultimate function of the tracer be to guide a tool which operates in a path of finite width (as for example the path cut out from work by a cutting torch)—which width is frequently referred to as the "kerf" generated by the tool—then for correspondence of either of the edges left by the tool with the indicium it is necessary to provide a lateral displacement in order to effect compensation for half that kerf. It is further well understood as desirable that the first of these provisions be for an adjustable lead, in order for example that the lead may be varied in accordance with tracing speed, and that the second of these provisions be for an adjustable half-kerf, in order that tools respectively generating different kerfs may readily be accommodated.

While for at least the latter of these provisions various other expedients have been proposed, optical expedients for both have been proposed and are in general to be preferred. Various such expedients have for example been disclosed in U.S. Patent No. 3,037,888 issued June 5, 1962. One of these optical expedients has been the interposition of a dual-mirror assembly or a prism (either wedge-shaped or parallel-face) element between the indicium and the projecting lens, the optical axis of the lens typically coinciding with the abovementioned axis about which the photoelectric means is angularly movable. The dual-mirror assembly has been cumbersome in structure and adjustment and has found little acceptance. The wedge-shaped prism element has in fact (though not always in idealized illustration!) complicated and confused the optics of the system by causing the optical axis of the projected light rays as it exists on one side of that prism element to be not merely displaced from but also inclined relative to that axis as it exists on the other side of that element, and has not lent itself readily to adjustment of the displacement except by removal and replacement by a differently-shaped element—or by rotation about a normal to the indicium surface, in which case the adjustment of lead displacement undesirably influences the adjustment of kerf displacement and vice versa. The parallel-face prism element, although avoiding the first two of these difficulties and theoretically providing for a progressive adjustment of displacement, is in practice limited to very modest displacements unless serious optical distortions and lack of image definition are to be tolerated; rotation about the normal to the indicium surface in no way cures these shortcomings, and furthermore would entail the abovementioned interdependence of lead and kerf adjustments.

Another of these optical expedients has been an adjustable inclination, of the optical axis of the projected rays, away from the fundamental normal relationship to the indicium-bearing surface, the photoelectric means being meanwhile unaltered in orientation in the carriage. This inclination has been proposed to be effected by an adjustable displacement of the projecting lens transversely to its axis, either with or without a maintenance of that axis normal to the indicium-bearing surface. I have observed that the practice of this expedient results in serious disadvantages. Thus if the lens be displaced transversely to its axis with that axis maintained normal to the indicium-bearing surface, the axis of the projected light rays from the indicium to the photoelectric means (of course, after the carriage has been dynamically repositoned along the indicium-bearing surface in the manner which that displacement will have commanded) will be inclined to the lens axis; this imposes the requirement for a lens of much higher correction than otherwise needed and, in the absence of compliance with that requirement, results in an impairment of definition in the image at the photoelectric means. The same unfavorable consequences will occur if the lens be displaced by being swung about pivots substantially closer to the lens than is the photoelectric means, and they will be avoided only in the special case of displacement of the lens by swinging it about pivots aligned with the photoelectric means.

But the disadvantages do not stop there. In any case of transverse displacement of the lens by swinging of the lens to incline its axis, while leaving the photoelectric means unaltered in orientation, there will occur other unfavorable results, importantly including (a) an impairment of the ability to adjust the displacement without refocusing the image, and (b) an impairment of the ability to achieve good image definition with respect to an indicium (e.g. a line) of appreciable width. Considering as to (a) simply the point in the indicium at which the lens axis intersects the indicium and the corresponding point in the image, the inclining of the lens axis effects an increase of the distance from that indicium point to the effective center of the lens, resulting in a decrease of the distance from the corresponding image point to the lens center—yet the distance from the point on the photoelectric means where that image point should fall (of course, after the carriage has been dynamically repositioned along the indicium-bearing surface in the manner which the inclining will have commanded) to the lens center will also have increased, thus necessitating a refocusing to bring the image point into coincidence with the photoelectric means. Considering as to (b) a transverse line across a finite-width indicium intersecting the lens axis and a corresponding line in the image, the inclining of the lens axis in a plane transverse to the indicium causes the distance from a first end of the indicium transverse line to the lens center to be increased and the distance from the second end of that line to be decreased, resulting in a decrease of the distance of the first end and an increase of the distance of the second end of the image line from the lens center—in turn resulting in a marked tipping of the image line, out of the throughout-its-length coincidence with the photoelectric means which it may be assumed to have had before the inclination, which tipping in spite of any refocusing seriously impairs the definition at the photoelectric means other than at some one point on the image line. These impairments (a) and (b) are in no wise minimized by increasing the correction of the lens; they can of course be minimized by restriction of the aperture of the lens to increase its depth of focus—but this, resulting in a tremendous loss of light received by the photoelectric means, is ordinarily an intolerable cure.

It is an object of the invention to provide, in a tracer, an arrangement of photoelectric means and lens which permits adjustment of lead and/or of kerf compensation in a manner minimizing the abovementioned disadvantages and complications. It is an object to provide a structure which permits adjustment of lead and/or kerf compensation in an improved, simplified and more dependable manner. Allied and other objects will appear from the following description and the appended claims.

I have found that the abovementioned disadvantages and complications of the lens-axis-inclination technique may be obviated to a large degree, and in measure ample to render wholly satisfactory two discrete adjustable inclinations of the lens axis (one for lead and one for kerf compensation), if the photoelectric means and the projecting lens both be included in an integral opticoelectric system which is adjustably inclinable, preferably in each of two right-angularly-related planes, as a unit.

In the detailed description of the invention hereinafter set forth reference is had to the accompanying drawings, in which:

FIGURE 1 is a plan view of a tracer of the type disclosed in the abovementioned patent application, in which my invention may be embodied;

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 and including a schematic showing of the electric circuitry of the tracer on a broad functional basis;

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

FIGURE 5 is an enlarged vertical cross-sectional view taken along the line **5—5** of FIGURE 2;

FIGURE 6 is a generally vertical cross-sectional view taken along the line **6—6** of FIGURE 5;

FIGURE 7 is an enlarged generally horizontal view taken upwardly along the line **7—7** of FIGURE 5 when the tracer is in process of tracing a line; and

FIGURE 8 is a view similar to FIGURE 7 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 that surface, in any suitable manner. By way purely of simple schematic illustration of means for exerting those 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 funciton 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 may be 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 view of FIGURE 1 the indicium appears as the line L; the tool appears as the torch T, supplied with useful by the hose H, directed 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 and secured in spaced relation to and above the platform **11**; and a member **13** extending upwardly, for example at the right hand end of the platforms **11** and **12**.

A mount **20** for the traction wheel **30** is journalled 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 FIGURE 4, this mount may comprise a relatively thick-walled tube **21** to which is 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 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 extending toward the axis. The traction wheel **30** may be mounted on a shaft **31** journalled 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 5, 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 journalled therewithin suitable bearings of which the lower one on'y 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, and in that boss there may be journalled a shaft **35** on which there 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 the 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**, gear **38** and shaft **31**.

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. There may be mentioned as desirable the use of a driving motor **40** of the well-known so-called Lee type, whose speed is maintained quite closely constant through serially arranged governor-operated contacts.

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 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 seeen at the axis of the mount **20** (and thus at any other point fixed in 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, and such an offset is contemplated in the illustrated tracer.

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 carries photoelectric means and a lens for projecting upwardly thereon to an image of a longitudinal segment of the indicium. These elements may be mounted to a barrel **50** which is itself seen in elevation in FIGURE 3; for an illustration of these elements mounted thereto, however, reference may be had to FIGURES 5 and 6. Therein the photoelectric means, designated generally as **70**, appears near the top of the barrel, while the lens **65** appears at a position somewhat below the bottom of the barrel. The photoelectric means and the mounting of it and the lens to the barrel are hereinafter described in greater detail.

The barrel **50**, which may be of greater diameter in its lower than in its upper portion, is journalled in the carriage about an axis parallel to that of the mount **20**. 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 barrels **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 described, by the photoelectric means **70**.

For the scanning of a line indicium the photoelectric means preferredly comprises two photoelectric devices **71** and **72**, which in turn are preferredly of the light-modulated-resistor variety each typically in the form of a small cylinder in one end of which a light-sensitive area is disposed. The two devices **71** and **72** may be peripherally contiguous to each other, with their parallel axes lying in or approximtely in the plane of FIGURE 6. Optically the devices **71** and **72** may present toward the lens **65** coplanar disc surfaces on which respective central rectangles **71***a* and **72***a* form light-sensitive areas, as seen in FIGURE 7; each of these rectangles, which along their major dimensions are aligned with each other, may typically extend along that dimension for about three-quarters of the diameter of the device.

By the lens **65** there will be projected onto the plane of the light-sensitive areas **71***a* and **72***a* an image of the indicium which appears on the surface S (here assumed to be a line of finite width). The lengthwise direction of the image is such as to render the line between the centers of the areas, and thus their mutually aligned major dimensions, transverse to the image; FIGURE 7 illustrates as I a shaded strip representing that image for the line indicium L of FIGURE 1. Advantageously, the width of the line indicium and the degree of magnification of the image relative to the line are so chosen that marginally the image may partially overlie each of the areas **71***a* and **72***a*.

Illumination of the portion of the indicium of which the image is projected may for example be provided by an electric bulb **5** contained in a housing **7** carried at the lower end of an adjustable gooseneck **8** secured at its upper end to the platform **11**, the housing being for example provided with a suitable condensing lens **6** for the concentration of light from the bulb **5** onto the surface S underneath the projecting lens **65**.

In order to make electrical connections from stationary circuitry to the terminals of the photoelectric devices, which are mounted to 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 slip rings **77** respectively connected to the terminals of the photoelectric devices. Electrical connections to these slip rings and therethrough to the device terminals may be made through 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.

As shown in FIGURE 3, the slip rings **77** and thus the photoelectric devices may be electrically connected into a balanceable electric circuit **80**, energized for example by A.C., from which the output may be connected to the input of an A.C. amplifier **90** supplied with requisite D.C. from the D.C. supply **100** (preferably of regulated variety). The A.C. output from the amplifier **90** may be supplied to the control phase or winding of the servo motor **110**, a center-tap on that winding being for example connected to the positive terminal of the D.C. supply **100**. The servo motor **110** will of course also have a reference phase or winding 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 electric circuit **80**.

A regulable mechanico-electric negative or stabilizing feedback may be 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 supplied with alternating current of the same phase as that supplied to the balanceable electric circuit **80**; it may have its output phase or winding connected across a potentiometer **118** from which a regulable fraction of the tachometer output may be introduced into the balanceable electric circuit **80** for algebraic addition therein to the output voltage therefrom.

A fuller description of the electric circuitry thus briefly described, including typical internal details of the balanceable electric circuit **80** and the A.C. amplifier **90**, are to be found in the allowed Purkhiser patent application above referred to.

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 lens **65** 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 **71***a* and **72***a* the dark image I of the indicium in the laterally centered position illustrated in FIGURE 7; under these conditions the fractions of the respective areas **71***a* and **72***a* covered by the dark image are equal, the lighted fractions of those areas are equal, and the resistances of **71** and **72**, assuming them to be of the light-modulated-resistance variety, are at least nearly equal. The balanceable electric circuit **80** will previously have been adjusted so that under these conditions there will be zero voltage output from that circuit and therefore no input to or output from the amplifier **90** 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 the axis of lens **65** from the center of the line indicium. If and when a departure begins, one of the areas **71***a* and **72***a* will become slightly less covered and the other slightly more covered by the image; the resistance of one of the devices **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 of the balanceable electric circuit **80** and the 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 lens **65** 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 lens **65** strongly constrained to remain aligned with the lateral center of the line indicium, and 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 here will be exerted (through gear **52**) a control of the angular position of the barrel **50** and thus of the photoelectric means **70**, the result of which is to maintain the mutually aligned major dimensions of the areas **71***a* and **72***a* 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.

While the foregoing detailed description describes a type of tracer with which my invention may be employed to great advantage, it is to be understood that the invention is not in all aspects limited to a tracer of that type.

There may now be described the mounting of the photoelectric means **70** and of the lens **65** to the barrel **50**—which according to the invention is effected in an improved manner, inter alia providing for lead and kerf-compensation adjustments obviating or minimizing such disadvantages as were introductorily mentioned above—reference being had particularly to FIGURES 5 and 6. In this connection it is helpful to recall 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, and to observe that FIGURE 5 shows the barrel **50** and its associated components in the angular position occupied when the mount **20** occupies the angular position—of coincidence of the plane of wheel **30** with that of the figure—in which it is illustrated in FIGURE 4.

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 5, 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 6 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 the adjusting screw **56** provides for limited orientation of the axis of the tube **52** 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 6, there are secured a pair of inwardly directed studs **58** pointing toward each other, on whose inner end portions there is pivoted a generally vertical tubular member **61**. 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 may be made coincident with that of tube **51**; its axis may, however, be rocked appreciably away from such coincidence, and within limits any deesired degree of divergence from such coincidence may be established by suitable adjusting means. Such means have been shown in FIGURE 5 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 within which the tube-**51** axis may be oriented.

It is in the bottom of the tubular member **61** that the lens **65** is mounted, desirably coaxially with that member; the dimensioning of the various components is such as to place this lens at a distance from the surface S somewhat greater than the focal length of the lens. It is at the top of the tubular member **61** that the photoelectric means **70** are mounted; to provide for this mounting there may be telescoped around and there may extend a short distance upwardly from the tubular member **61** a tube **68**, secured as by a clamping screw **67** (whose head is accessible through a suitable aperture in the barrel **50**) passing therethrough into the member **61**, and having its upper end closed by a relatively thick cap member **69**—it being in the cap member **69** that the photoelectric means **70** are mounted. To provide for a limited axial adjustability of the photoelectric means—for the purpose of accurate focusing of the image on the light-sensitive areas of the photoelectric means—the aperture in the tube **68** through which the screw **67** passes may be vertically elongated.

The tubular member **61**, with tube **68** and cap **69**, and the lens **65** and the photoelectric means **70** may be considered as constituting a unitary optico-electric system **60**—in which the photoelectric means is fixed in orientation with respect to the axis of the lens, although that means may be limitedly moved along that axis for focusing. According to the invention the adjustments for lead and for kerf compensation are effected by adjustably inclining that system as a unit relative to a normal to the surface S, the lead adjustment being effected by rocking the tubular member **61** about the studs **58** and the kerf-compensation adjustment being effected by rocking the tube **51** (to which the tubular member **61** is mounted) about the studs **55**.

FIGURE 5 illustrates the adjustment for lead. Herein V indicates a normal to the surface S from the axis of studs **58**, while A indicates the axis of the lens (which axis intersects the photoelectric means at the midpoint between the light-sensitive surfaces **71***a* and **72***a*). In the figure it will be seen that the axis A has (by the adjusting screws **59**) been rocked away from the normal V so as to intersect the surface S slightly (in the illustration, somewhat exaggeratedly) in advance of that normal V. This of course is an adjustment of the axis in a plane (that of the figure) transverse to the surface S and extending along the indicium.

FIGURE 6 illustrates the adjustment for kerf compensation. Herein V′ indicates a normal to the surface S from the axis of studs **55**, while A again indicates the axis of the lens. In the figure it will be seen that the axis A has (by the adjusting screw **56**) been rocked away from the normal V′ so as to intersect the surface S at a point spaced away from the intersection of V′ with that surface by half the kerf cut by the tool (e.g. the torch T of FIGURE 1). This of course is an adjustment of the axis in a plane (that of the figure) transverse both to the surface S and to the indicium. It will of course be understood that the direction (left or right) of displacement of the axis A in FIGURE 6 will be chosen according to whether the piece of the work which is to be accurately formed is on one side or the other of the cut—e.g. whether in FIGURE 1 that piece is the central piece Z or the portion of the work W surrounding the path P of the torch.

By maintaining the orientation of the photoelectric means fixed with respect to the axis of the lens, rather than with respect to the mount **50**, I obviate or minimize the disadvantages introductorily discussed, and I upgrade the optics of the system both in respect of function and in respect of ease—and ready understandability by the operator of the tracer—of its adjustment.

The tube **51** and the studs **55** by which it is pivoted and the studs **58** by which the optico-electric system is pivoted to it may be considered as constituting a set of gimbals for the mounting of the optico-electric system in the barrel **50** and thus in the carriage.

For the tracing of an edge indicium the photo-electric means may comprise a single photoelectric device, which might of course be mounted with its center on the axis of the lens (i.e. where the devices **71** and **72** are tangent to each other); such a positioning would, however, entail a replacement of a portion of the tracer in changing from line to edge tracing or vice versa. With a lens of moderate correction it is possible to use for edge tracing a single photoelectric device displaced (in the direction mechanically opposite to that of travel of the carriage) somewhat from the axis of the lens and thus capable of being incorporated int he same structure with the pair of devices **71–72** already described, and a single device so positioned has been illustrated in the drawing as **73**; this may be similar to each of the devices **71** and **72**, and may have its light-sensitive area **73***a* arranged parallel to the light-sensitive areas of those devices. (When the device **73** is used for edge tracing, rather than the devices **71–72** for line tracing, certain electrical switching must be performed within the balanceable electric circuit **80**; this, fully described in the above-mentioned allowed Purkhiser application, is not described herein because forming no part of the present invention.)

FIGURE 7 being a view prepared to illustrate line tracing, the device **73** therein may be considered surplusage as far as the present invention is concerned. FIGURE 8 is a view prepared to illustrate edge tracing (and therein in the devices **71** and **72** may be considered as surplusage). Here it will be seen that the light-sensitive area **73***a* of the device **73** is crossed by the image J of the infinitesimal-width edge indicium, rendering that area partially dark and partially light, and this is the condition maintained during the operation of edge tracing (analogously to the maintenance of the image I in line tracing partly overlying each of the areas **71***a* and **72***a*). FIGURE 5 illustrates as B the line along which the lens **65** will project an image of a segment of the indicium onto the light-sensitive area **73***a* of the device **73**. In the absence of readjustment about the pivots **58** the line B will provide a somewhat increased amount of lead; this is usually desired in edge tracing, relative to line tracing—but in any event the amount of lead may readily be readjusted as desired by a readjustment of the optico-electric system about the pivots **58**.

While I have disclosed my invention in terms of a particular embodiment thereof, I do not intend thereby any unnecessary limitations. Modifications in many respects will be suggested by my disclosure to those skilled in the art, and such modifications will not necessarily constitute a departure from the spirit of the invention or from its scope, which I undertake to define by the following claims.

I claim:

1. In apparatus for tracing an elongated indicium, including a carriage propellable over a surface bearing the indicium, the combination of main and intermediate support members movable in said carriage, an elongated housing, an optical-electric system mounted in said elongated housing and comprising photoelectric means and a lens between said photoelectric means and said surface for projecting onto the photoelectric means an image of a longitudinal segment of the indicium, said elongated housing pivotably mounted in the intermediate support member for pivoting in a first plane, said intermediate support member pivotably mounted in said main support member for pivoting in a second plane, said main support member being angularly movable within the carriage about an axis normal to said surface to align the photoelectric means with the longitudinal segment of the indicium, and electric means connected with and controlled by the photoelectric means determining the direction of propulsion of the carriage and controlling the angular position of the support member.

2. The subject matter claimed in claim **1** wherein said first and second planes are perpendicular with one of said planes being transverse to the segment of said indicium.

3. The subject matter claimed in claim **1** wherein said optical electric system further comprises means for altering the distance between said photoelectric means and said lens to provide for focusing of said image on said photoelectric means.

4. The subject matter claimed in claim **1** wherein said elongated housing comprises a generally tubular member in which said photoelectric means and said lens are mounted.

5. The subject matter claimed in claim **4** wherein said lens is substantially coaxial with said tubular member.

6. The subject matter claimed in claim **1** wherein said pivotal connections between said elongated housing, intermediate support member and main support member comprise gimbals.

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U.S. Cl. X.R.

250—239

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,499,155 Dated March 3, 1970

Inventor(s) George R. Turbett

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 2, line 11, "carirage" should be --carriage--
Column 5, line 1, "funciton" should be --function--
Column 5, line 11, the word "useful" should be --fuel--
Column 5, line 54, after "therewithin" insert the word --in--
Column 6, line 20, the word "seeen" should be --seen--
Column 6, line 52, the word "barrels" should be --barrel--
Column 8, line 32, after the word "and" delete the word "the"
Column 8, line 51, the word "here" should be --there--
Column 9, line 23, "52" should be --51--
Column 10, line 62 "int he" should be --in the--
Column 11, line 3, delete the word "in"
Column 11, line 4, "Here" should be --Herein--

SIGNED AND SEALED OCT 6 - 1970

(SEAL)
Attest:

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Commissioner of Patents