Dec. 23, 1952 M. MARTELLOTTI 2,622,485

AUTOMATIC LINE TRACKING MACHINE

Filed June 16, 1950 4 Sheets-Sheet 1

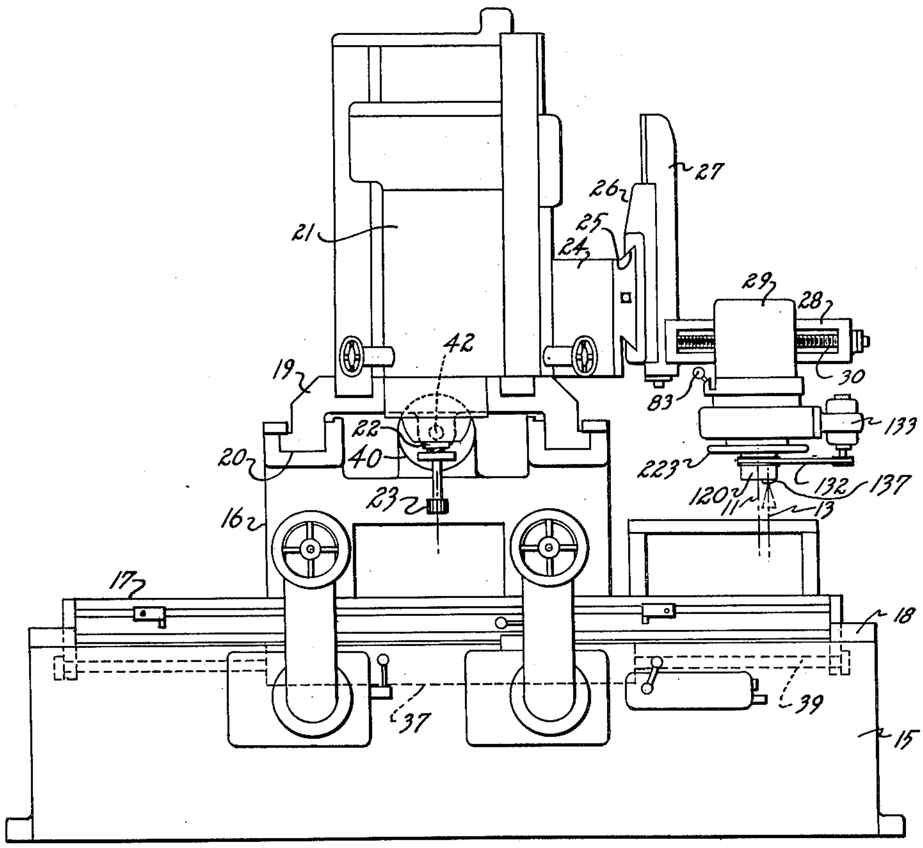

Fig. 1

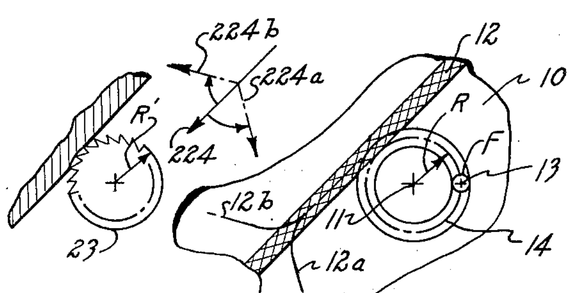

Fig. 6

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AUTOMATIC LINE TRACKING MACHINE

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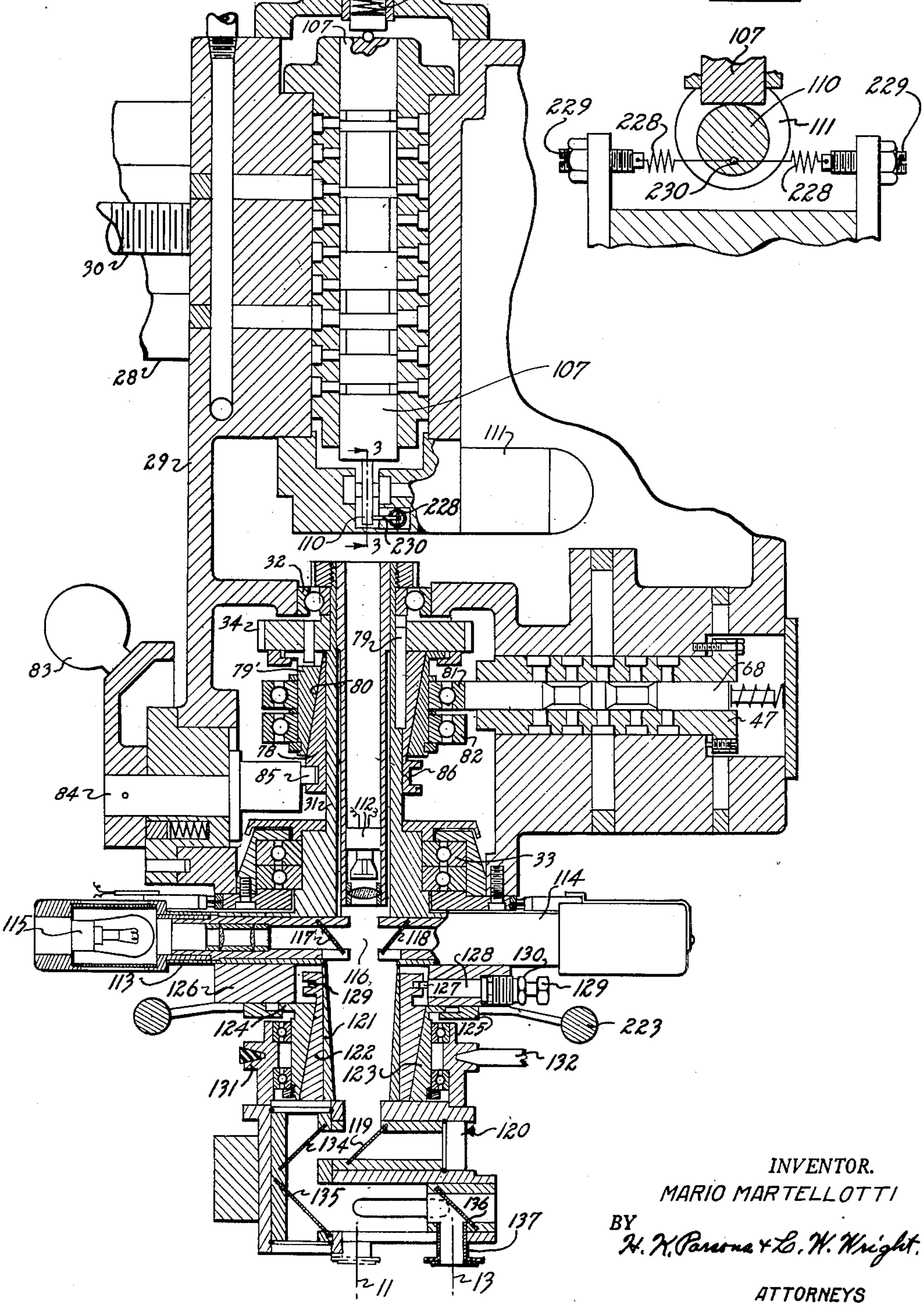
Fig. 2

Fig. 3



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AUTOMATIC LINE TRACKING MACHINE

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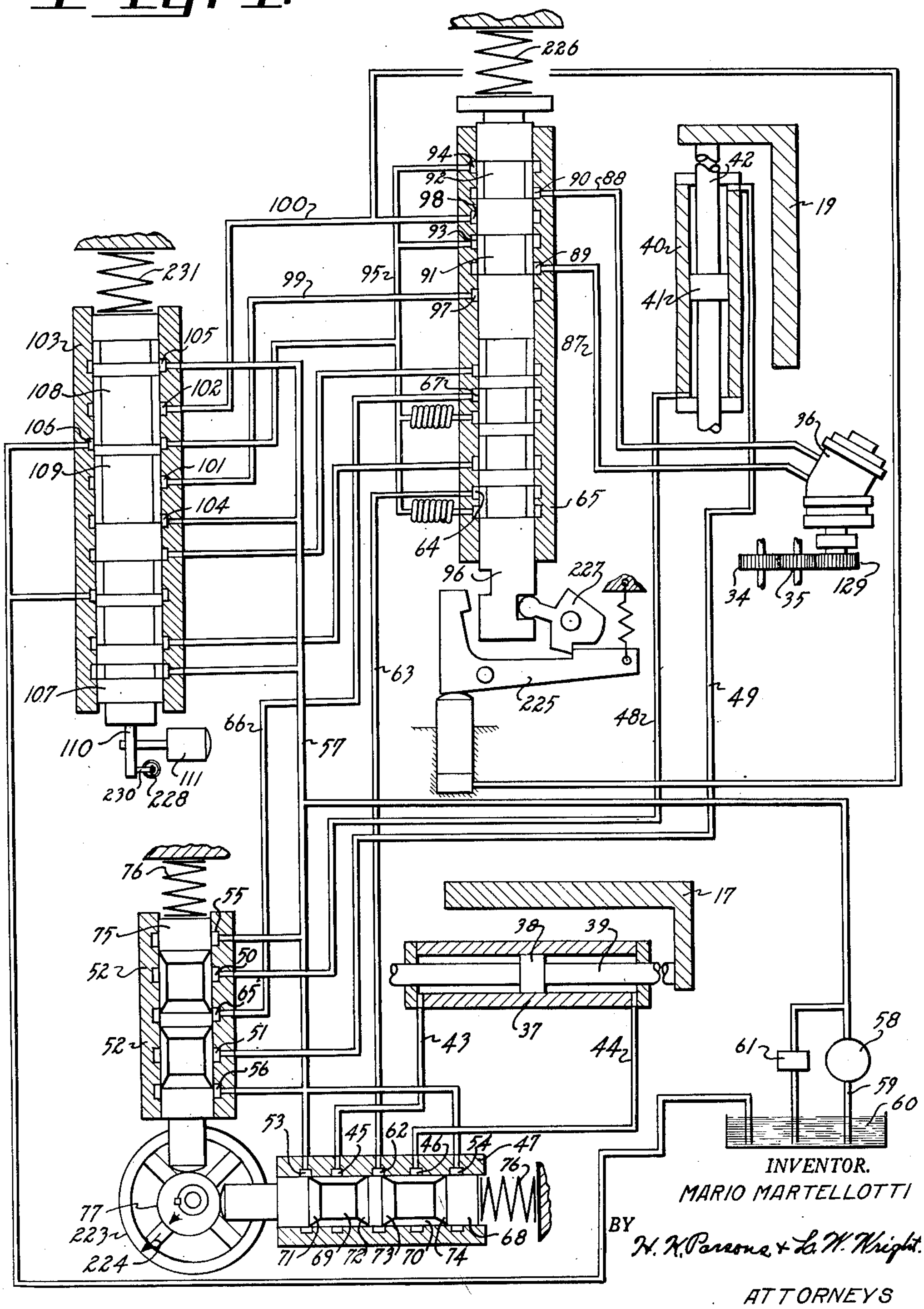
Fig. 4.



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AUTOMATIC LINE TRACKING MACHINE

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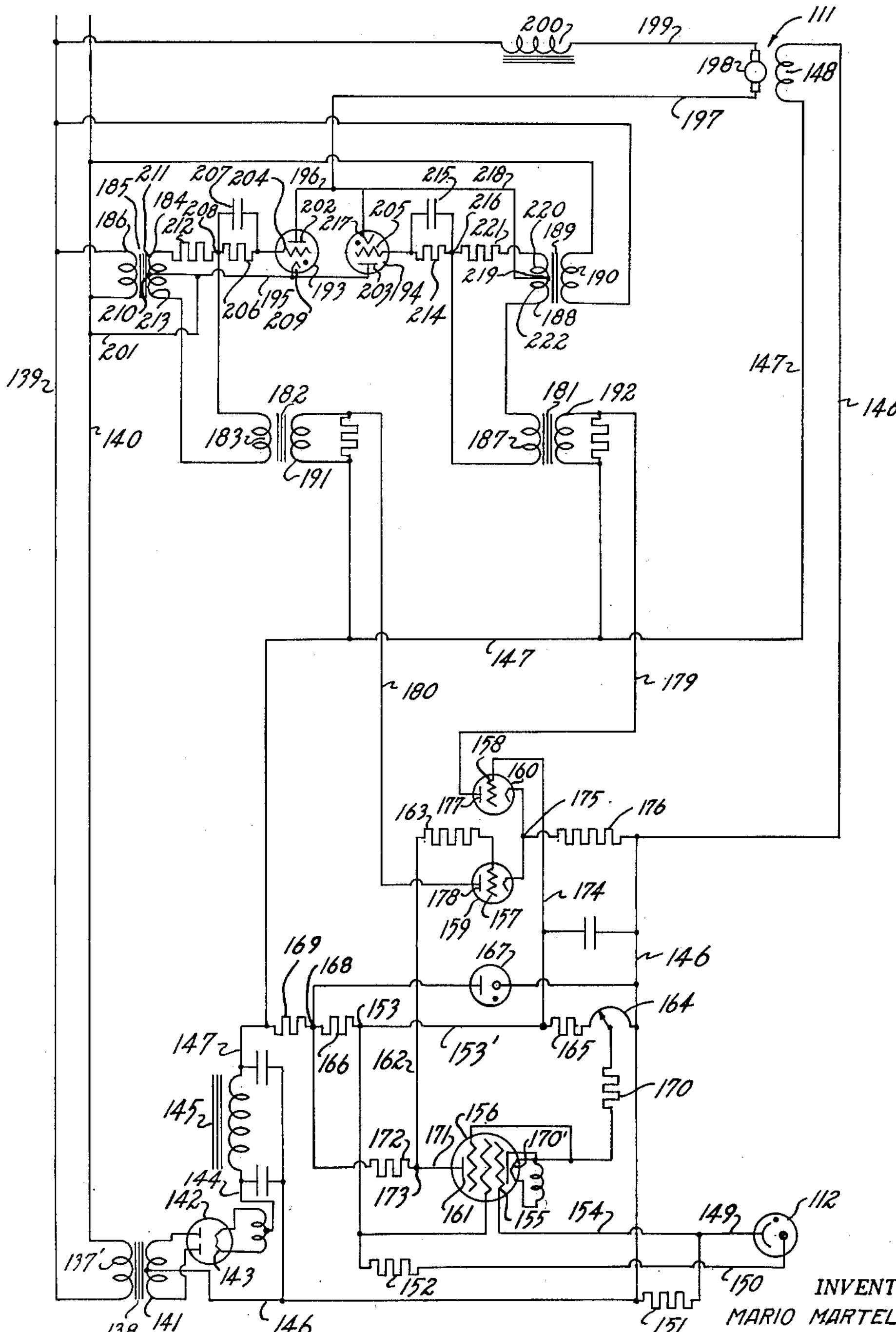

Fig. 5

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2,622,485

AUTOMATIC LINE TRACKING MACHINE

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Application June 16, 1950, Serial No. 168,443

5 Claims. (Cl. 90—13.5)

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This invention relates to automatic contouring machines in which a line acts as the pattern controlling element.

It has been conventional practice in this art to utilize as the pattern or control element some form of solid object of the desired shape or contour as the controlling pattern element and to utilize a tracer element in physical contact with the pattern to continuously sense the direction in which the cutting path is to be generated.

There is now developing a demand for a reproducing machine which will eliminate the necessity for making or building a pattern and instead to control the machine directly from a line drawing, which formerly was utilized in making the pattern. By so doing, the intermediate step of making a pattern is eliminated and thus the cost of producing the work is greatly reduced, especially where only a small number of work pieces are to be reproduced from a given pattern.

Reproducing machines designed for following a line are sometimes known as line tracking machines, and, in general, fall into two classes, in one of which, the tracer or sensing means makes physical contact with the drawing and in the other, the sensing means is of such a nature that it is not necessary to make physical contact with the drawing.

This invention relates to the latter type of machine, and more particularly to one in which light or radiant energy is utilized as the sensing means, and although the sensing means does not, in one sense, make physical contact with the line, it is the means which controls or causes the machine to follow a contour and thus in that sense traces or scans the contour, and in this specification is intended to have that meaning.

It is an object of this invention to provide an improved automatic line tracing mechanism of the type utilizing radiant energy as the sensing or control medium.

Another object of this invention is to provide a new and improved mechanism for automatically following an outline or contour without the necessity of physical contact therewith.

A further object of this invention is to provide an improved optical system including a photoelectric cell to maintain follow of the line and detect changes in its direction and correspondingly effect directional control changes in the driving mechanism.

Another object of this invention is to devise an electrical pick-up or scanning system which may be combined with a hydraulic driving system for automatic control thereof to effect contour milling.

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Other objects and advantages of the present invention should be readily apparent by reference to the following specification, considered in conjunction with the accompanying drawings forming a part thereof, and it is to be understood that any modifications may be made in the exact structural details there shown and described, within the scope of the appended claims, without departing from or exceeding the spirit of the invention.

Referring to the drawings in which like reference numerals indicate like or similar parts:

Figure 1 is a front elevation of a reproducing machine embodying the principles of this invention.

Figure 2 is a section through the tracer head of the machine shown in Figure 1.

Figure 3 is a detail section on the line **3—3** of Figure 2.

Figure 4 is a diagrammatic view of the hydraulic operating circuit.

Figure 5 is a diagram of the electrical control circuit.

Figure 6 is a diagrammatic view, showing the relationship of the scanning path to the line being followed and the cutter being controlled.

For the purpose of greater clarity in understanding this invention, it is desirable to review the fundamental principles of a lens or, in its more complicated form, a telescope. Such devices are sighted on an object and thereby produce an image. A telescope may be adjusted or focused to encompass a small circular area in the objective plane, and this small circular area is defined and referred to in this specification as the field of view and for purposes of illustration may be illustrated in the drawings as a small circle F as shown in Figure 6.

If the objective surface **10**, in which this circle lies, is a good reflector and is illuminated, the maximum flow of reflected light or radiant energy from the circular field of view will pass to the telescope and thus to a photo-electric cell optically connected therewith. It is contemplated in this invention to impart a planetary motion to this field of view about an axis **11** normal to the objective plane or surface and to so relate the parts that once during each revolution, or travel through its orbit, the field of view will overlap or scan a portion of a contour line **12** being followed.

A very good arrangement is to make the objective surface a good reflector, and the line thereon a poor reflector, thus establishing a differential between the reflective capacities of each. It should now be evident that by establishing a predetermined overlap of the line per revolution, the total flux of radiant energy per revolution passing to the photo-electric cell will be less than the maximum referred to supra, but it is capable of being increased by less overlap of the line, or by being decreased by more overlap of the line.

By means of this invention, a photo-electric cell is connected and adjusted in accordance with the amount of light received for the predetermined overlap condition, and the voltage generated by the cell for this condition can be considered as the reference voltage. It now becomes possible for this voltage to automatically increase in response to a decrease in overlap of the line as a result of more light passing to the cell; or for the voltage to automatically decrease in response to increase in overlap of the line as a result of less light passing to the cell.

It has been found practical that rather than illuminate a large area in the objective plane, excellent results can be obtained by confining the illumination to the field of view because the strong concentrated illumination on a small area reduces the effects of variations from the lights and shadows around the machine. This spot illumination is made to follow the scanning orbit or travel of the field of view, and thus, in effect, it would appear to be a rotating spot of light. It will now be seen that by arranging a light sensitive cell, such as a photo-electric cell, in proper position to receive the reflected radiant energy, and by providing an objective area of high reflectibility, and a contour line thereon of low reflectibility, that once each revolution an impulse will be received by the photo-electric cell acting to reduce its voltage.

In accordance with this invention, means are provided for revolving the field of view at a predetermined fast rate with the result that the photo-electric cell is caused to generate a pulsating direct current voltage. Although this voltage is pulsating, it will actually produce an average effective voltage, otherwise known as a root mean square voltage, which may be adjusted to establish a known reference voltage for a predetermined overlap of the line. Under such a condition, either an increase or a decrease in the amount of overlap will cause a decrease or an increase in the effective output voltage of the cell. These variations above or below the reference voltage are utilized as signals to control operation of the machine, and cause the cutting tool to follow a cutting path in accordance with variations in the contour line being followed.

A satisfactory machine for embodying the principles of this invention is shown in Figure 1 of the drawings. In this illustrated machine the reference numeral 15 indicates a bed from the rear of which uprises a column 16. A table 17 suitable for supporting a work piece or the like and a pattern or drawing to be reproduced is slidably mounted on suitable guideways 18 formed on the top of the bed 15.

A cross slide 19 is suitably supported on guideways 20 formed on the top of the column 16 for movement crosswise of the table. A spindle carrier 21 is slidably mounted on suitable guideways formed on the front face of the cross slide 19. The spindle carrier journals a spindle 22 and is adapted to be driven by conventional power transmission mechanism for rotating a cutting tool 23.

The spindle carrier, which moves vertically, is provided with a bracket 24 projecting from the side of the spindle carrier for supporting a tracer mechanism so that the tracer mechanism is responsive to both the vertical movements of the spindle carrier and the cross movements of the slide 19. The bracket 24 is provided with a dovetailed guideway 25 upon which is mounted a cross moving slide 26, and this slide, in turn, supports and guides a vertically movable slide 27 which is of right angular shape and has a horizontal guideway 28. The scanning mechanism housing, indicated generally by the reference numeral 29, is slidably mounted on the guideway 28 and may be adjusted along the guideway by the adjusting screw 30. It will be noted from the relationship of these guideways that the scanning housing may be adjusted in any one of three directions in space relative to the spindle carrier and primarily with respect to the cutting tool 23 so that the tracer mechanism and the cutting tool may be properly aligned with respect to corresponding points on the work and pattern.

A vertical section through the scanning housing is shown in Figure 2 in which the reference numeral 31 indicates a tubular main carrier member which is supported in the housing against axial movement on anti-friction bearings 32 and 33. This member carries a gear 34 attached thereto whereby it may be operatively connected for rotation through suitable gearing 35, Figure 4, to a prime mover such as a hydraulic motor 36.

This motor is not a continuously rotating motor but is a directional control motor and oscillates to maintain the resultant direction of feeding movement in accordance with the direction of the particular section of the contour line being followed.

It will be obvious, since the direction of feeding movement may be at any angle throughout 360 degrees in a horizontal plane, that any angular direction of movement must be the resultant of the different rates of movement of the table and the cross slide. As shown in Figure 4, the table 17 may be actuated by a hydraulic motor of the piston and cylinder type comprising a cylinder 37 which is suitably fixed in the bed 15 and a contained piston 38 connected by a piston rod 39 to the end of the table 17.

The cross slide 19 may be similarly powered by a piston and cylinder motor comprising a cylinder 40 which is suitably fixed in the column 16 and a contained piston 41 connected by a piston rod 42 to the slide 19.

These cylinders are connected to individual rate and direction control valves, that is, the cylinder 37 has its opposite ends connected by hydraulic channels 43 and 44 to motor ports 45 and 46 of valve 47. Similarly, opposite ends of cylinder 40 are connected by channels 48 and 49 to motor ports 50 and 51 of valve 52. The valve 47 has pressure ports 53 and 54, and the valve 52 has pressure ports 55 and 56 and all of these pressure ports are connected to a common pressure line 57 which is supplied by a pump 58. This pump has an intake 59 for withdrawing hydraulic fluid from a suitable reservoir 60 and the delivery of the pump has a relief valve 61 connected thereto for controlling the delivered pressure of the pump. The valve 47 has an exhaust port 62 which is connected by channel 63 to port 64 of a control valve 65, and similarly, the valve 52 has an exhaust port 65′ which is also connected by channel 66 to port 67 of the control valve 65.

The valve 47 has a valve plunger 68 in which is formed annular grooves 69 and 70 forming tapered spools 71, 72, 73, and 74 which act to variably throttle the flow through the various ports. When the valve plunger 68 is in a central position with respect to port 62 the various tapered spools slightly underlap the respective ports 53, 62, and 54 whereby there is a small continuous flow from the pressure port 53 to the exhaust port 62 and from the pressure port 54 to the exhaust port 62, and this creates an intermediate pressure in the two grooves 69 and 70 which are substantially equal and which are communicated through channels 43 and 44 to opposite ends of the piston 38, thereby holding the piston against movement.

Similarly, the wave 52 has a valve plunger 75 of the same construction so that in a central position equal pressures are established in channels 48 and 49 and thereby on opposite ends of piston 41 to hold the same against movement. The valve plungers 75 and 68 are held by springs 76 against a control cam mechanism 77. This cam may be eccentrically adjustable from a position of zero eccentricity in which the valve plungers are held in a neutral position, to a position of maximum eccentricity, and by selecting the amount of eccentricity the rate of slide movement and thereby the relative feeding rate between the tool and the work may be determined.

Rotation of the cam inversely adjusts the valve plungers 75 and 68 in such a manner as to determine the direction of relative movement between the tool and work.

This cam mechanism is mounted on the rotatable member 31 previously described in connection with Figure 2. Briefly, this mechanism consists of an inner truncated cylinder 78 which is operatively connected by a spline 79 to both the member 31 and gear 34. Thus, the member 78 will simultaneously rotate with the gear 34 and the member 31. An outer member 79′ has an inclined bore 80 fitting the shape of the member 78 whereby as the member 78 is slid up or down on the member 31 it will cause the outer member 79′ to move laterally or eccentrically with respect to the axis of the member 31. The outer member carries two anti-friction bearing rings 81 and 82 which are engaged respectively by the ends of the valve plungers 68 and 75 and serve as cams for controlling them, and thus constitute the cam mechanism 77.

The inner member 78 is manually adjusted up and down by means of the control lever 83 mounted on the end of a shaft 84 which has an eccentric pin 85 located in the end thereof for engaging the shifter groove 86 of the inner member 78. Thus, by means of the rate control lever 83 the eccentricity of the cam mechanism may be manually set, and the automatic rotation of the cam mechanism by the gear 34 will determine the resultant direction of relative movement between cutter and work. As previously stated, the rotation is effected by the motor 36 shown in Figure 4, and this motor is connected by a pair of channels 87 and 88 to ports 89 and 90 of the interlock control valve 65, which serves as a starting valve for initiating automatic feeding by the machine.

In the stop position of the valve, as shown, the ports 89 and 90 are connected by valve grooves 91 and 92 to ports 93 and 94 which lead to the return channel 95. When the valve plunger 96 of valve 65 is moved downward to its running position, the ports 89 and 90 are connected by the grooves 91 and 92 to ports 97 and 98 which, in turn, are connected by channels 99 and 100 to motor ports 101 and 102 of the master control valve 103. This valve has two pressure ports 104 and 105 which are supplied from the pump 58, as well as an exhaust port 106. The valve plunger 107 of this valve has a pair of annular grooves 108 and 109 for alternately connecting the pressure ports 104 and 105 to the motor ports 101 and 102. The position of this valve is controlled by eccentric cam 110 shown in Figure 3, which is oscillated by an electric motor 111. This motor is the connecting link between the electrical scanning system shown in Figure 5 and the hydraulic operating system shown in Figure 4. In other words, the control signals from the photo-electric cell are utilized to operate this motor, which, in turn, through valve 103 controls rotation of the hydraulic motor 36, which, in turn, sets the direction of feeding movement through cam mechanism 77.

The photo-eelctric scanning system is carried by the member 31 including the photo-electric cell and the means for creating a spot of light, and this system is connected by the electrical circuit shown in Figure 5 in a manner to control rotation of the electric motor 111 and thereby control the operation of the machine. The photo-electric system comprises a photo-electric tube 112 which is suitably mounted in the axial bore of the member 31. In addition, the member 31 supports two tubular members 113 and 114 arranged normal to its axis of rotation, and in the outer end of each of these tubular members is mounted a source of light in the form of a light bulb 115.

At the intersection of these tubular members with the axial bore 116 of the member 31 there are mounted two mirrors 117 and 118 which are angularly positioned at such an angle that light from the bulbs 115 passing through the tubes 113 and 114 will be reflected downward by the respective mirrors to a mirror 119. This mirror is positioned substantially at an angle of 45 degrees of the axis of the member 31 and the mirror is carried by a separate rotatable head indicated generally by the reference numeral 120. The member 31 has a lower cylindrical section 121 upon the periphery of which is mounted a truncated cylinder 122 which is vertically slidable on the portion 121. A cooperating member 123 has a diagonally extending bore fitting the periphery of the member 122 and at such an angle that upon axial adjustment of the member 122 the member 123 may be adjusted eccentrically with respect to the axis of rotation of the member 31.

The member 123 is held against axial movement by means of a flange 124 formed on its upper end which overlaps a flange 125 carried by the part 126 which is integral with the member 31 and which is rotatable therewith.

The member 122 is shifted axially by a pin 127 formed eccentrically on the rotatable member 128 which is also mounted in an integral part of the member 31. The pin 127 engages a shifter groove 129 formed in the periphery of the upper end of the member 122.

The member 128 has a hexagonal head 129 whereby it may be rotated, and a sleeve lock nut 130. The object of eccentrically adjusting the member 123 is that a drive pulley 131 is anti-frictionally mounted on the periphery of the member 123 and is driven by a belt 132 which is connected to an electric motor 133 which, as shown in Figure 1 of the drawings, is carried by a fixed part of the tracer housing 29. By eccentrically adjusting the member 123 the slack in the belt 132 may be taken out, thereby insuring a more positive drive. The pulley 131 has the rotatable head 120 integrally secured to its lower end, whereby the head 120 may be rotated at a continuous fast rate independent of the slow rotation or oscillation of the member 31.

The head 120 supports a pair of mirrors 134 and 135 which are angularly related so that light striking the mirror 119 will be reflected by the mirror 134 to the mirror 135, and this, in turn, will reflect the light to a mirror 136 located in the upper end of the sighting tube 137. This tube may contain suitable lenses, if necessary, to concentrate the light.

Reflected light from the pattern will return through the tube 137 and be reflected, in turn, by the mirrors 136, 135, 134, and 119 to the axial bore 116 of the member 31 and thereby to the photo-electric cell 112 located in the upper part of the bore of the member 31.

Variations in light intensity on the photo-electric cell 112 are translated by the electrical circuit shown in Figure 5 into motion of the master control valve motor 111. To this end a source of rectified D. C. current is obtained by connecting the primary 137′ of a transformer 138 to a source of A. C. indicated by the lines 139 and 140. Opposite ends of the secondary 141 are connected to separate plates of the by-phase valve rectifier tube 142. The cathode 143 of this tube is connected by line 144 to a filter indicated generally by the reference numeral 145. A line 146 is connected to the midpoint of the secondary 141 and constitutes the negative side of the rectified D. C. circuit, while the line 147 forming the output from the filter represents the positive side of the D. C. circuit.

These two lines are directly connected to opposite ends of the field 148 of the motor 111. Thus, the field of the motor is continuously energized by rectified D. C. current.

The terminals 149 and 150 of the photo-electric tube 112 are connected across the D. C. circuit, the terminal 149 being connected by a resistor 151 to line 146, and the terminal 150 being connected by a resistor 151 to line 146, and the terminal 150 being connected by a resistor 152 to a source of constant potential at 153. The plate of the photo-electric tube is connected by line 154 to the control grid 155 of pentode tube 156. This tube forms part of an amplifying circuit for controlling the grids 157 and 158 of tubes 159 and 160 in the sense that the variations in the rather weak current from the photo-electric cell are enabled to control and cause variations in the plate circuit of the tube 156.

The plate 161 of tube 156 is connected to the grid 157 of tube 159 through line 162 and resistor 163. The grid 158 of tube 160 is connected by line 174 to a source of constant voltage represented by the line 153. A voltage regulator tube 167 is connected between line 146 and a point 168, this point being connected to the D. C. output line 147 by the resistance 169 so that a steady D. C. voltage is obtained between the points 168 and the line 146, any variance in voltage will now appear across the resistance 169. It will now be seen that there is a constant voltage circuit from line 146 through rheostat 164, resistor 165, line 153′, and resistor 166 to the point 168. By means of the rheostat 164, a voltage is selected for the cathode circuit of tube 156, the rheostat being connected through a resistor 170 to the cathode 170′. The plate 161 of tube 156 is maintained positive by its connection through line 171 and resistor 172 to the constant voltage point 168 which, in turn, is connected to positive D. C. line 147 by resistor 169.

Thus, with a steady potential on the grid 155 and by adjusting the rheostat 164 to give a desired potential on the grids of tubes 159 and 160 which are substantially equal, a predetermined starting condition for operation of the circuit may be established.

The cathodes of the tubes 159 and 160 are connected to a common point 175 which, in turn, is connected by a resistor 176 to the negative D. C. line 146 which thereby establishes a negative potential on the cathodes.

There will now be an equal flow of current from the negative line 146 through resistor 176, through the parallelly connected tubes 159 and 160 to the plates 177 and 178 of the respective tubes which plates, in turn, are connected by lines 179 and 180 to separate saturable reactors 181 and 182 to control the flow of A. C. current through the reactors. Since a small direct current in the D. C. winding of a saturable reactor can control a large flow of A. C. current through the reactor, it will be seen that an amplifying effect is obtained since small variations in the D. C. current of the control tubes 159 and 160 is made to effect variations in the large flow of A. C. current in the reactors.

These reactors are operatively connected to the motor 111, one reactor for causing rotation of the motor in one direction, and the other reactor for causing rotation in the opposite direction.

When the illumination on the photo-tube 112 increases above a predetermined norm, determined from the predetermined overlap of the line, it causes the reference voltage on grid 155 to rise, and more current will flow from line 146 to the constant voltage point 168. The increased flow of current through the tube 156 lowers the potential at point 173 and thus lowers the potential of the grid 157 of tube 159. This will decrease the current flowing through tube 159. This, in turn, will increase the cathode potential at point 175 and increase the flow of current in the tube 160 because the grid potential in this tube remains constant.

By keeping the potential on the grid 158 substantially constant, the grid 157 of the other tube may be varied with respect to it, and in so doing controls the flow through tube 160 indirectly by raising or lowering the cathode potential of the tube as represented by the point 175.

It should now be evident that the photo-electric cell directly controls the grid potential of one tube 159, and thus the flow of current therethrough, and indirectly and inversely controls and varies the current flow through the other tube, 160, by controlling or varying the cathode potential of that tube. By this unique arrangement when the current flow through one tube is increased, the current flow through the other tube is automatically decreased.

The saturable reactor 182 has its A. C. winding 183 connected to opposite ends of a secondary 184 of an A. C. transformer 185, the primary coil 186 of which is connected to the A. C. supply lines 139 and 140. Similarly, the reactor 181 has its A. C. winding 187 connected to opposite ends of the secondary 188 of an alternating current transformer 189, the primary coil 190 of which is connected to the A. C. supply lines 139 and 140.

The plate circuit 180 from tube 159 is connected to one end of the direct current winding 191 of the reactor 182, while the other end is connected to the positive D. C. line 147. Similarly, plate circuit 179 from tube 160 is connected to one end of the D. C. winding 192 of reactor 181, while the other end is connected to the positive

D. C. line 147. Thus, when the D. C. current in the winding 191 is increased, the alternating current flow through the A. C. winding is simultaneously increased, but at the same time the D. C. current will be decreased in the D. C. winding 192 of the reactor 181, decreasing the A. C. current flow through the winding 187.

A pair of Thyratron tubes 193 and 194 are connected back to back between line 195 and line 196. Line 196 is connected by branch line 197 to the armature 198 of the motor 111, the other end of the armature being connected by line 199 and inductance 200 to the A. C. supply line 139. The line 195 is connected by a branch line 201 to the A. C. supply line 140.

Thus, we have an armature circuit starting from the A. C. line 140 through lines 201 and 195 to the two tubes 193 and 194, and from these tubes through lines 196 and 197 to the armature 198, the circuit being completed through line 199 and inductance 200 to the other A. C. line 139. Since the tubes 193 and 194 are connected back to back, current will flow through the tube 193, when the tube is fired, in the direction toward its plate 202, thus causing or tending to cause rotation of the armature in one direction, while current flow in the tube 194 toward its plate 203, will cause or tend to cause rotation of the armature 198 in the opposite direction. The firing of these tubes is controlled by their grids 204 and 205 respectively.

Each grid circuit is connected across a bridge to obtain a phase changing effect. The grid 204 of tube 193 is connected by a grid resistor 206 and a grid condenser 207 arranged in parallel to a point 208, forming one midpoint of the bridge. The cathode 209 of tube 193 is connected by line 195 to point 210 forming the other midpoint of the bridge circuit. One leg of the bridge, between points 208 and 210 includes one-half of the secondary 184 indicated by the reference numeral 211, and the fixed resistor 212. The other leg includes the other half of the secondary 184 indicated by the reference numeral 213, and the A. C. winding 183 of the saturable reactor 182. It will be noted that the A. C. winding 183 constitutes the variable part of the bridge circuit.

Similarly, the grid 205 is connected by a grid resistor 214 and grid condenser 215, arranged in parallel, to a point 216 forming one midpoint of the bridge. The cathode 217 of tube 194 is connected by line 218 to point 219 forming the other midpoint of the bridge. One leg of the bridge circuit from point 219 includes one-half 220 of the secondary 188 and the fixed resistor 221. The other leg includes the other half 222 of the secondary 188 and the A. C. winding 187 of the saturable reactor 181. It wil be noted that the A. C. winding 187 constitutes the variable element of this bridge circuit.

When the same D. C. voltage is applied to each saturable reactor by the tubes 159 and 160, the Thyratron tubes 194 and 193 will fire at the same time. By properly adjusting the voltage the tubes will fire at the same point in the cycle, preferably midway of the positive half of the A. C. cycle. The result, however, will be that the amount of current flowing from the plate 202 into line 197 will be equal to the amount of current flowing in the opposite direction, that is, from the line 197 to the cathode of tube 194. These currents will balance one another and therefore no rotation will be produced in the armature 198 of motor 111.

When, however, the D. C. current on one reactor is increased, and on the other reactor decreased, by the tubes 159 and 160, the effect on the reactors in their respective bridge circuits is to cause one of the tubes 193 or 194 to fire ahead of the other, whereby a flow of current in one direction through line 197 is created for a greater time than the current flowing in the opposite direction, thus producing rotation of the motor. Obviously, the direction in which the greater current flows through line 197 determines the direction of rotation of the motor.

As previously set forth, the motor 111 and its connected cam 110 controls the position of the master control valve plunger 107 shown in Figures 2 and 4 of the drawings. Normally, during operation of the machine, this cam is in its neutral position, that is, in a position to hold the master control valve in its neutral position and thus cause the hydraulic motor 96 to remain stationary.

In setting up the machine for operation, the machine slides are adjusted to put the spot of light in the necessary relationship with respect to the line to be followed.

Referring to Figure 6, very satisfactory results can be obtained by spacing the axis 13 of the sighting tube 137 from the edge of the line 12 a radial distance R equal to the radius R^1 of the cutter 23. Since the cutter and sighting tube are on the same support for joint movement, they will always be in the same relation to corresponding points on the work and pattern. The circle 14 represents the path of travel or orbit of the axis 13 which is the center of the field of view, and by keeping this circle tangent to the line being followed, one-half of the field of view will overlap on the line each revolution. This makes a very satisfactory or normal condition for tracing or following the line.

Under the conditions illustrated in Figure 6, the feed direction setting of the directional control cam 77 is represented by the arrow 224. If the line deviates from this direction, as represented by the line 12*a*, then the overlap of the line would increase, and an automatic adjustment would be effected to change the direction of feed of the cutter to that represented by the arrow 224*a*. When the line deviates as represented by the line 12*b*, the overlap of the line by the field of view is decreased and an adjustment is effected to change the direction of feed to that represented by the arrow 224*b*.

The sighting tube 137 is slidably mounted in its upport so that the radius R may be adjusted to suit the radius of the cutter utilized therewith.

It will now be seen that each revolution of the spot of light or field of view will intersect or overlap a predetermined portion of the line, and the electrical circuit is adjusted for this condition so that the electric motor 111 will be balanced and held against rotation.

The hand wheel 223, which is operatively connected to the member 31 carrying the cam 77, is rotated or adjusted so that the direction arrow 224 on the hand wheel, as shown in Figure 4, points in a direction substantially parallel to the line to be followed. The start valve 96 is moved to its lower position by clockwise rotation of the bell crank 225, as shown in Figure 4, and a spring 226 will move the plunger down upon release of the latch 227. This will result in operatively connecting the hydraulic motor 36 to the master control valve, but with the master control valve in neutral position no rotation of the hydraulic motor would take place. The control cam 77 is now eccentrically adjusted by its control 83 to establish a given feed rate in the direction as determined by the arrow 224.

With the electric motor 133 set into operation for rotating the scanning tube, the feeding movement between the tool and work continues in the direction in accordance with the relative position of the two directional control valves 47 and 52, their positions being determined by the cam 77.

With the electric lights 115 illuminated to create the spot of light it will be seen that the photo-electric cell starts to function and be responsive to variations in the amount of light reflected from the field of view as variations occur caused by increase or decrease in the amount of line overlap caused by variations in the direction of the line. It has been described in connection with the electrical circuit shown in Figure 5 how increases or decreases in the amount of reflected light on the photo-electric cell cause rotation of the electrical motor 111 in one or the other direction to position the control cam 110 and move the valve plunger 107 above or below its neutral position. If it moves below its neutral position, such as that shown in Figure 4, fluid pressure from the pump 58 will flow through port 104 and groove 109 of the valve plunger to motor port 101 so that the fluid pressure will continue through line 99, interconnected ports 97 and 89 of valve 65 and line 87 to the hydraulic motor 36.

The return fluid will pass through line 88, interconnected ports 90 and 98 of valve 65 to line 100 and pass to reservoir through interconnected ports 102 and 106 of the master control valve. This will cause rotation of the cam 77 in the proper direction to reposition the directional control valves and thereby change the direction of relative movement between the tool and work to make it conform to the new direction of the particular line section being followed. If the master cam 110 is rotated in a direction to raise the master control valve above its neutral position, the motor port 101 will then become an exhaust port through interconnection with port 106 and the motor port 102 will be connected to pressure through its interconnection with port 105. The result will be that the cam 77 will be rotated in the opposite direction.

When the change in the direction of feed has been brought into parallelism with the portion of the line being followed, it will be obvious that the reaction on the photo-electric cell will neutralize the electrical circuit to hold the parts in their new position.

It will be noted at this point, that just previous to the neutralization of the electric circuit, that the motor 111 has been driving the cam 110 in one direction or the other and therefore at the moment of neutralization of the circuit the control valve is off center with respect to its neutral position. It is, therefore, necessary to immediately return the valve to its neutral position in order to stop further rotation of the hydraulic motor.

This is accomplished by providing centralizing springs 228 as shown in Figure 3 which are attached at one end to adjusting screws 229 threaded in a fixed part of the motor support, and at the other end, connected to a pin 230 projecting from the face of the cam 110. The springs are adjusted to hold the cam and thereby the control valve in its neutral position. Thus, when the valve is moved to an off-center position and the motor 111 deenergized, the springs will rotate the cam as well as the motor armature immediately to reposition the valve plunger 107 with the aid of spring 231 to its neutral position and stop further rotation of the hydraulic motor 36.

Thus, the action of the motor 111 is always that of moving the master control valve out of its neutral position to start actuation of the hydraulic motor to change the direction of feed while the neutralizing springs act to return the control valve to its neutral position and thus hold the direction control mechanism in its new position.

There has thus been provided a new and improved device of the character described, which is particularly useful for machining irregular shapes from a line drawing and which embodies a new and improved system for following a line, and one which is contrived so that it may control a hydraulic actuating system for the working elements of a machine and govern the direction of generation of a cutting path in accordance with the line being followed.

What is claimed is:

1. In a machine tool having a pair of slides movable normally one with respect to the other and a rotatable cutter carried by one of said slides for operation on work carried by the other slide, the combination with power operable means for moving said slides, of means on said other slide for supporting a pattern surface having a contour line delineated thereon, means on said one slide for rotating a spot of light on said surface about an axis spaced from the edge of said line substantially equal to the radius of said cutter to effect a predetermined overlap of the spot of light on said line once each revolution, a photo-electric cell operatively connected for continuously viewing said spot of light and establishing a reference voltage in accordance with the average reflected illumination from said pattern per revolution of the spot of light and, a control circuit for said power operable means operatively connected to said cell and responsive to variations in voltage with respect to said reference voltage for determining the direction of relative movement effected by said power operable means between the cutter support and work support.

2. A machine for causing relative movement between two supports to reproduce a contour comprising, in combination, means on the one support for supporting a pattern surface having a delineated line thereon forming the contour to be reproduced, means for projecting a spot of light on said surface, power operable means for rotating said projecting means about an axis of revolution spaced from the edge of said line to effect periodic overlap of the line by said spot of light, a photo-electric cell optically connected for continuously viewing the spot of light and establishing an average reference voltage for the average return of light per revolution, and a control circuit operatively connected to the cell having means responsive to voltage variations with respect to said reference voltage for controlling the direction of said relative movement.

3. A machine for causing relative movement between two supports to reproduce a contour having, in combination, means on one support for supporting a pattern surface having a delineated line thereon forming the contour to be produced, a tracer mechanism carried by the other support including an enclosed photo-electric cell, a line

viewing tube optically connected to said cell and having an optical axis normal to said pattern surface, said tube being adjusted to have a field of view on said pattern forming a scanning circle, means defining the axis of revolution for said tube eccentric to its optical axis, said axis of revolution being spaced from the edge of said line, means to adjust said tube relative to its axis of revolution in accordance with the radius of the cutter utilized therewith, means for illuminating the area of said circle, means for rotating said tube about said axis of revolution to effect periodic overlap of the circle on said line and establish a reference voltage in said cell, and means to utilize increases or decreases in voltage with respect to said reference voltage as correction signals for determining the direction of said relative movement.

4. A machine tool for causing relative movement between two supports to reproduce a contour comprising in combination means on the one support for supporting a pattern surface having a delineated line thereon forming the contour to be reproduced, means projecting a spot of light on the pattern surface, power operable means for rotating said projecting means about an axis spaced from said line to effect periodic overlap of said spot of light on said line per revolution, a photo-electric cell continuously responsive to reflected light from said spot for establishing an average reference voltage for a predetermined overlap of said line, whereby changes in voltage with respect to said reference voltage may be utilized as control signals for determining changes in the direction of said relative movement.

5. In a machine tool for causing relative movement between two supports to reproduce a contour from a delineated line on a pattern surface carried by one support, the combination of means for automatically controlling the direction of relative movement between said supports comprising a scanning tube optically connected to a photo-electric cell for scanning the marginal area adjacent said line, means to illuminate the area being scanned, means to rotate said tube about an axis intersecting said area to effect periodic overlap of said line to modify the flux of radiant energy passing to the photo-electric cell per revolution and establish a predetermined average control voltage, and electrical means responsive to increases or decreases in said voltage to change the direction of said relative movement.

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