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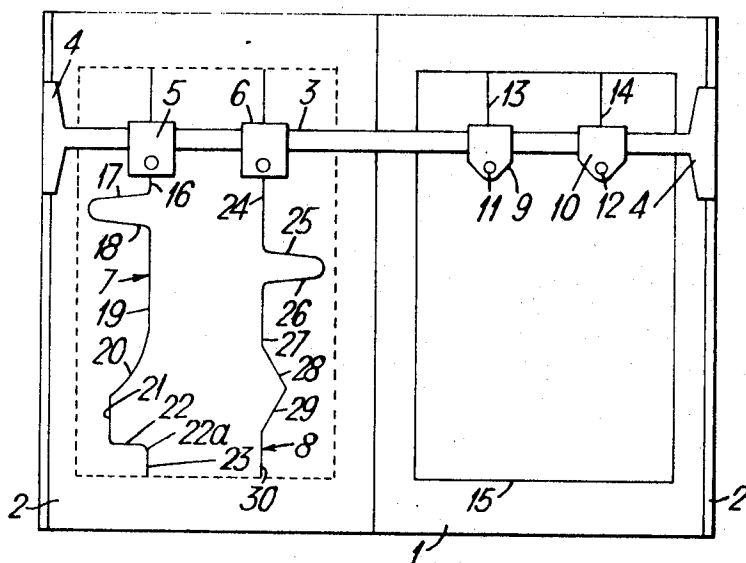
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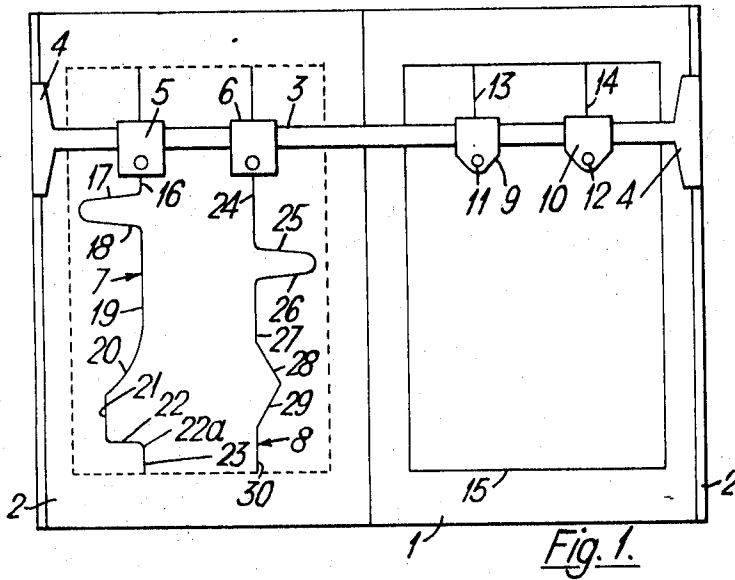
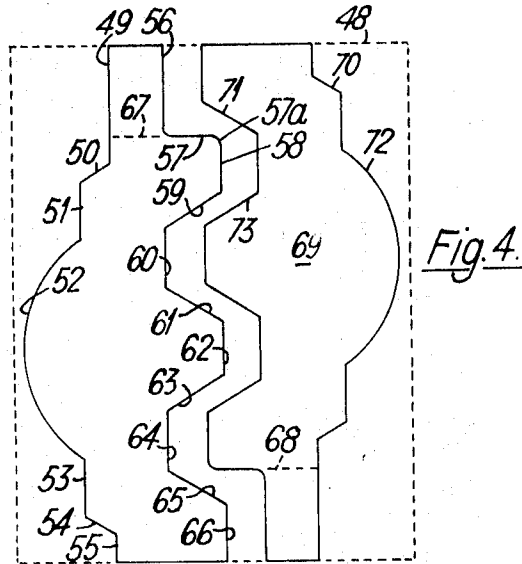
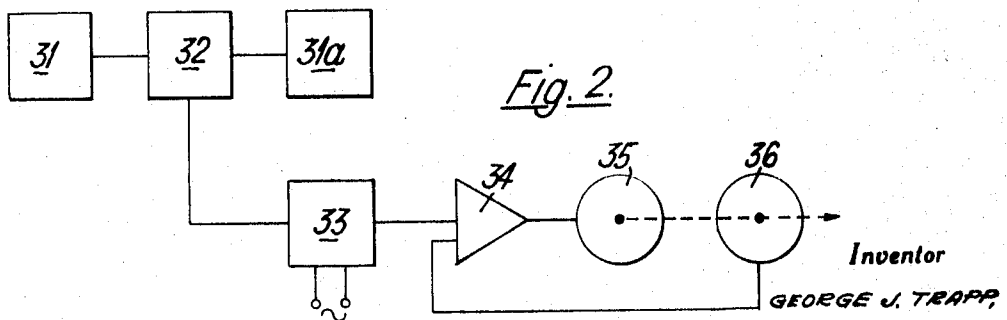
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[54] **METHOD AND APPARATUS FOR
SIMULTANEOUSLY FOLLOWING A PLURALITY
OF OUTLINES**
13 Claims, 7 Drawing Figs.

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219; 33/18; 83/71; 90/62; 144/144, 144.5;
318/20.605, 20.655

ABSTRACT: Method and apparatus for simultaneously following a plurality of separate outlines by means of separate photoelectric line followers mounted for simultaneous longitudinal movement and independent transverse movement and each guiding a separate tool, in which movement signals from the line followers are compared, the signal which at any instant corresponds to the slowest longitudinal movement is selected, and the line followers are driven in the longitudinal direction at a speed related to the selected signal. In a modification one or more of the line followers may make reverse longitudinal movements while the others are stopped.





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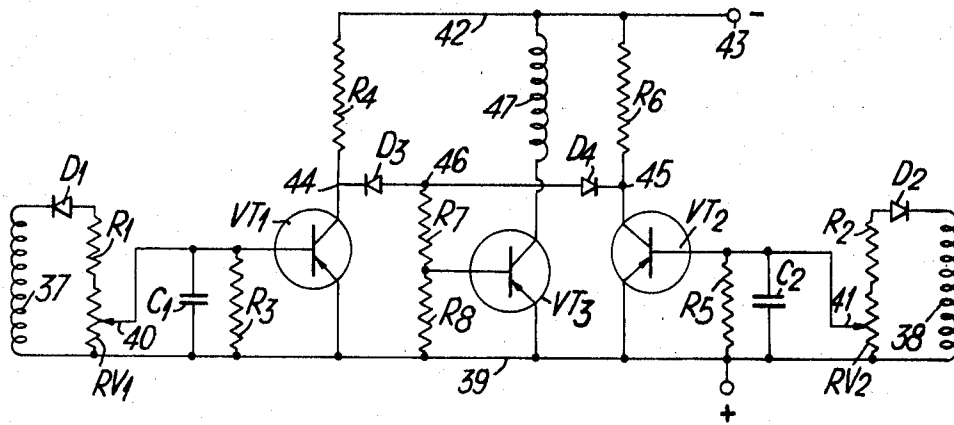


Fig. 3.

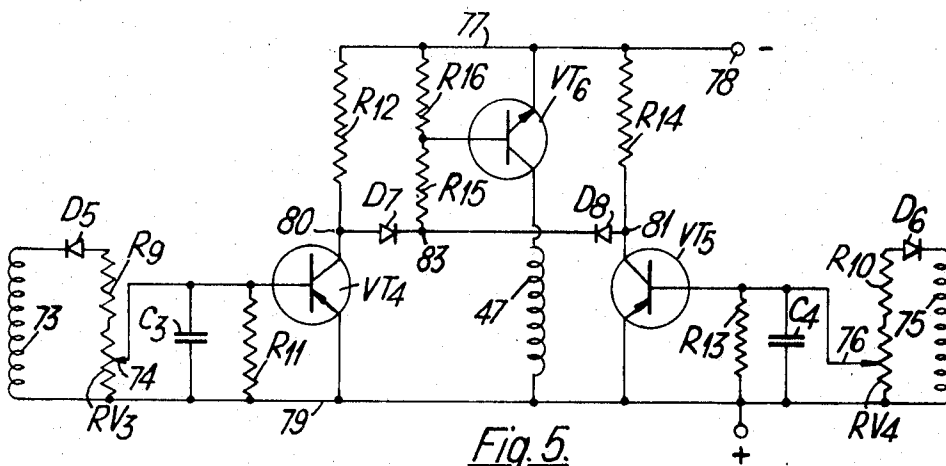


Fig. 5.

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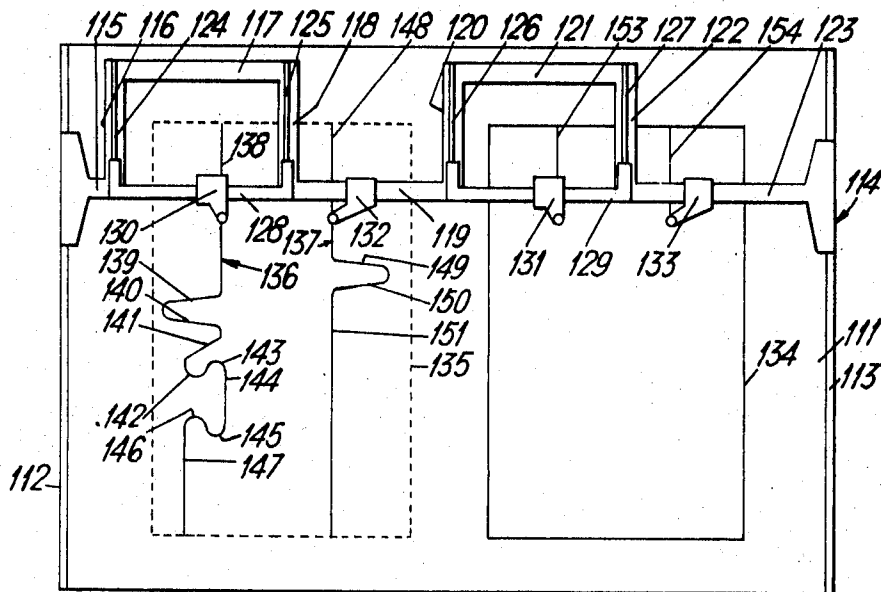


Fig. 6.

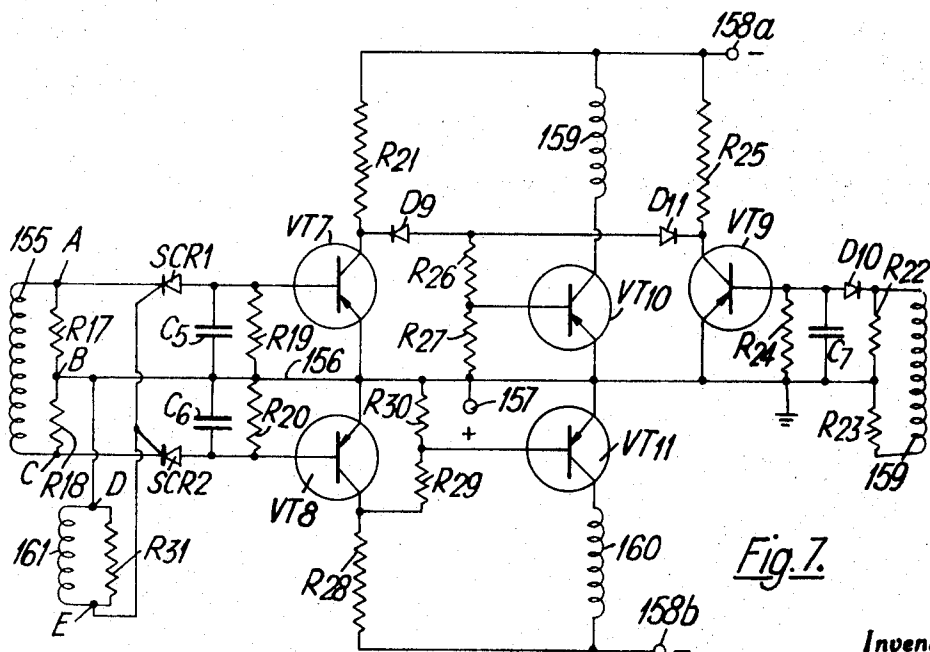


Fig. 7.

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METHOD AND APPARATUS FOR SIMULTANEOUSLY FOLLOWING A PLURALITY OF OUTLINES

This invention relates to speed control apparatus for a machine containing a plurality of photoelectric line following devices and an equal plurality of tools, in which each line follower is adapted to follow a separate outline and guide one tool, the line followers being so mounted that they travel simultaneously in a longitudinal direction of the machine and can move independently in a transverse direction to follow the respective outlines. While the apparatus according to the invention may be used for other purposes, it will be particularly described in relation to oxygen jet cutting machines.

It is well known to use an automatic photoelectric line follower in an oxygen jet cutting machine for cutting workpieces to desired shapes. The outline of the desired shape is carried upon a substrate, such as a sheet of drawing paper, which is mounted on a table or other support in the machine, and the line follower automatically follows the outline and at the same time guides the oxygen jet flame cutter which cuts a workpiece of corresponding shape from a piece of plate. The outline may be the same size as the workpiece to be produced, or it may be drawn to a smaller scale, in which case appropriate movement multiplying transmission means are incorporated to cause the cutter to cut a correspondingly larger shape.

The cutter of a flame cutting machine can cut a particular piece of plate at a certain maximum speed, depending upon the thickness of the plate being cut and the type of cutter being used. Where a single line follower is employed the apparatus is arranged so that the cutter moves at a constant speed over the plate, whatever its direction of movement, and this constant speed is equal to or close to the maximum speed at which the cutter is capable of cutting, in order to secure maximum efficiency in operation and the completion of each piece of work in a minimum time. In order to secure these conditions the line followers are arranged to provide two coordinate signals, one signal defining the longitudinal or Y speed and the second signal defining the transverse or X speed, the signals being related in a sine/cosine relationship which provides the desired constant maximum cutter speed in all directions. Separate motors are used to drive the followers and the cutters in the X and Y directions. If the desired cutter speed is 1 unit and the movements in the X and Y directions are x speed units and y speed units respectively the relationship between the speeds is at all times $x^2 + y^2 = 1$.

Where long workpieces are to be cut and the opposite sides are to be shaped, it is known to use two cutters mounted upon a carriage which is moved longitudinally (in the Y direction) of the machine, each line follower following its own outline and being adapted for independent transverse or X movement along the beam, and each controlling the transverse movement of one cutter. A difficulty arises in selecting the longitudinal speed at which the beam is moved in order that both followers may properly follow their outlines and both cutters may carry out their work correctly.

In one known arrangement the two cutters are mounted on a beam for simultaneous longitudinal or Y movement and independent transverse or X movement to follow the respective outlines, and means are provided for traversing the beam in the Y direction at a selected constant speed. From what has been said previously it will be evident if one of the outlines has a portion which is at a steep angle with respect to the Y direction the constant Y speed must be limited to that at which the respective cutter can cut the steeply angled portion, i.e., when it is moving at comparatively high speed in the X direction. Hence the machine will be operating inefficiently for most of its time and with many pairs of outlines it will take less time to cut the two outlines separately with a single cutter than to attempt to cut the two simultaneously.

In another known arrangement one line follower controls its own X movements and also controls the Y movement of the beam, while the second line follower only controls its own X

movements. Hence, if the second outline has a steeply angled portion the machine must be set so that the maximum longitudinal speed which the line follower can command does not exceed the low Y speed demanded by the steepest portion of the second outline. In this case also, the machine will be operating inefficiently for most of its time and it may be quicker to make two separate cuts with a single cutter.

The principal object of the invention is to provide a speed control system by which a plurality of line followers and tools (which may exceed two) is employed and the Y speed of the beam is so controlled that the machine operates at the maximum possible efficiency at all times, so that there is an important gain in efficiency by cutting a plurality of outlines simultaneously whatever the characteristics of the individual outlines may be.

Another object of importance is to provide a system in which one or more of the line followers and tools may be allowed to make reverse movements (as hereinafter defined) to a limited extent while still maintaining the maximum possible efficiency of machine operation.

The first object is achieved by allowing both (or all) of the line followers to produce Y movement signals and applying all the signals to circuitry which selects the signal representing the lowest Y speed and sets the longitudinal speed according to the selected signal. In this way it is ensured that one or other of the cutters is cutting at its maximum speed at any given instant, so that all the cuts are completed simultaneously in the shortest possible time.

In an alternative embodiment the X movement signals of all the line followers are compared and the Y speed is determined by the highest X movement signal, the circuitry being arranged to set the Y speed to an inverse function of the selected X movement signal.

The second object is achieved by providing a primary carriage for the Y movement and one or more secondary carriages supported on the primary carriage and capable of limited reverse Y movement with respect to the primary carriage, one line follower being carried by the or each secondary carriage, the other line follower or followers being carried by the primary carriage, the signal for a reverse movement by a line follower carried by a secondary carriage causing the primary carriage to be stopped while the secondary carriage carries out the reverse movement and restarted when the reverse movement signal ceases.

In one aspect the invention consists of a method of simultaneously following a number of outlines over which separate line followers are to be guided for the purpose of guiding separate tools, comprising the steps of deriving longitudinal and transverse movement signals depending upon the instantaneous direction of each of the outlines being followed, comparing the signals and selecting a signal which corresponds to the lowest longitudinal speed, and driving all the line followers in the longitudinal direction at a speed related to the magnitude of the selected signal.

In another aspect the invention consists of a machine comprising a carriage bearing a plurality of photoelectric line followers each adapted to follow a separate outline, the line followers being so mounted that they travel simultaneously in a longitudinal direction while each line follower may make independent transverse movements to follow the respective outline, the apparatus comprising means to receive movement signals from all the line followers, means to select a line follower signal corresponding to the slowest longitudinal movement, and means to control the speed of longitudinal movement of the line followers in accordance with the slowest longitudinal movement signal.

The signals may all be longitudinal movement signals, in which case the signal of smallest amplitude is selected to control the longitudinal movement, or the signals may all be transverse movement signals, in which case the signal of largest amplitude is selected and the line followers are driven in the longitudinal direction at a speed according to an inverse function of the selected signal.

In a further aspect the invention consists of a method of simultaneously following a number of outlines over which separate line followers are to be guided for the purpose of guiding separate tools, comprising the steps of deriving longitudinal and transverse movement signals depending upon the instantaneous direction of each outline being followed, comparing the signals and selecting a signal which corresponds to the lowest longitudinal speed, driving all the line followers in the longitudinal direction at a speed related to the magnitude of the selected signal, detecting a reverse longitudinal movement signal, stopping the longitudinal forward movement of all the line followers, driving the line follower which delivered the reverse movement signal in the reverse longitudinal direction until the reverse movement signal ceases, and then continuing the forward longitudinal movement of all the line followers.

In another aspect the invention consists of a machine comprising a primary carriage capable of longitudinal movement, at least one secondary carriage capable of forward movement with and reverse movement with respect to the primary carriage, one or more line followers supported on the primary carriage for movement therewith, one line follower mounted on the secondary carriage, all the line followers being capable of independent transverse movement in order to follow the respective outlines, means to cause the primary and secondary carriages to move forward while all the line followers are producing forward longitudinal movement signals, means to detect the production of a reverse movement signal by the said one line follower, means to stop the forward movement of the primary carriage while the secondary carriage performs the reverse movement, and means to restart the forward movement of the primary and secondary carriages when the said one line follower again produces a forward movement signal.

To promote a clear understanding of the invention selected embodiments thereof will now be described by way of example with reference to the accompanying drawings in which:

FIG. 1 shows diagrammatically an oxygen jet cutting machine containing a substrate bearing two outlines and a workpiece to be cut;

FIG. 2 is a block schematic diagram of the control apparatus for use with the machine of FIG. 1;

FIG. 3 is a circuit diagram for one form of control;

FIG. 4 shows the shape of two pieces to be cut simultaneously from a single plate;

FIG. 5 is a circuit diagram of another form of control circuitry;

FIG. 6 is a diagram showing an oxygen jet cutting machine so arranged that one line follower and cutter may make reverse movements; and

FIG. 7 is a circuit diagram of a control for the reverse movement arrangement.

FIG. 1 shows diagrammatically an oxygen jet flame cutting machine comprising a general framework 1 having longitudinal rails 2 at its sides and a transverse beam 3 forming a part of a carriage having end frames 4 containing wheels adapted to run along the rails 2. The beam 3 carries two line followers, respectively 5 and 6, arranged to execute transverse or X movements, that is, movements to and fro along the beam 3, in order to follow the respective outlines 7 and 8. The beam 3 also carries two cutter heads, respectively 9 and 10, each carrying oxygen jet flame cutter, respectively 11 and 12, there being means, either electrical or mechanical, by which the cutting head 9 is made to follow the X movements of the line follower 5, and the cutting head 10 is made to follow the X movements of the line follower 6. The beam 3 starts its longitudinal or Y movement from the top, as drawn in FIG. 1, and as shown, the cutters 11 and 12 have already made the first parts of their cuts, respectively 13 and 14. The workpiece itself is indicated by the rectangle 15.

The outline 7 consists of a straight portion 16, a rounded V portion having flanks, respectively 17 and 18, with an intervening curved portion, a further straight portion 19, a curved portion 20, a straight longitudinal portion 21 and a final

straight transverse portion 22 leading by a radius 22a into a final straight portion 23. The outline 8 has an initial straight portion 24, a rounded V-shaped portion having flanks 25 and 26, a straight portion 27, a broad V-shaped portion having sides 28 and 29 and a final straight portion 30. The edges of the substrate carrying the outline are indicated in dotted lines.

FIG. 2 is a block schematic diagram of one form of apparatus according to the invention in which the line followers deliver AC signals and the machine carriage is driven by an AC motor. The two followers are indicated respectively by references 31 and 31a. Either the Y (longitudinal) or X (transverse) signals from the line followers are applied to the selecting circuit 32, which supplies a control signal dependent upon the follower signal which represents the lowest Y speed. This control signal is applied through a magnetic amplifier 33 to a motor amplifier 34. The output signal of the amplifier powers a carriage motor 35 which drives the carriage in the Y direction. The motor 35 also drives a tachogenerator 36 which supplies a velocity feedback signal to the input of amplifier 34 in accordance with normal servopractice.

FIG. 3 shows one form of selecting circuit according to the invention designed to be fed with the Y signals or longitudinal speed signals from the line followers, the line followers being of a type which contain synchro or magflip resolvers to supply the X and Y signals. The two Y resolver windings 37 and 38 are connected through half-wave rectifiers or diodes, respectively D1 and D2, to a resistor in series with a potentiometer, respectively R1, RV1 and R2, RV2. The junction of each winding and potentiometer is connected to the ground and positive line 39.

The slider 40 of the potentiometer RV1 is connected to one side of a capacitor C1, the other side of which is connected to the ground line 39. The slider 40 is also connected to one side of a resistor R3 in parallel with C1 and to the base of a PNP transistor VT1. The emitter of VT1 is connected to ground line 39, while the collector is connected through a resistor R4 to a negative line 42 which is connected to the negative pole of a DC power source (not shown) via a terminal 43.

A PNP transistor VT2 is connected in precisely the same way in association with the other resolver winding 38, to resistor R5, capacitor C2, potentiometer slider 41, potentiometer RV2, resistor R2 and Diode D2, while the collector of VT2 is connected to the negative line 42 through a resistor R6.

The collector of VT1 is connected to the cathode of a diode D3 and the collector of VT2 is connected to the cathode of a diode D4, the anodes of D3 and D4 being connected together. A further resistor R7 is connected to the junction of these anodes and a resistor R8 in series with R7 is connected to the ground line 39. A PNP transistor VT3 has its base connected to the junction of R7 and R8, the emitter of VT3 being connected to the ground line 39. The collector of VT3 is connected to one end of the control winding 47 of the magnetic amplifier 33 and the other end of the control winding is connected to the negative line 42.

The resolver windings provide very powerful signals in relation to the required base signal of a transistor, hence the use of the resistors R1 and R2 and potentiometers RV1 and RV2. These could be replaced by voltage dividers composed of fixed resistors. In view of the large input signals the transistors TR1 and TR2 can be of the medium power type.

Assuming that the machine shown in FIG. 1 is in operation, and the windings 37 and 38 are respectively the Y signals windings of the resolvers in line followers 5 and 6, the line followers, when in the position shown in FIG. 1 produce maximum Y signals while following the portions 16 and 24 of the respective outlines. The signals from resolver winding 37 produce a half-wave rectified voltage across potentiometer winding RV1, a portion of which is tapped off and applied to the capacitor C1. The voltage drop across the resistor R1 applies a negative potential to the base of VT1 and this potential is stored in capacitor C1. Since the maximum Y signal is being received, VT1 conducts heavily and there is a large voltage drop along R4, so that the point 44, connected to the collector

VT1, is close in potential to the positive ground line 39. A transistor does not begin to conduct until the base (in the case of a PNP transistor) is negative with respect to the emitter by a small amount, and the values of resistors R7 and R8 are so chosen that when a maximum Y signal is applied with the voltage between the ground line 39 and the point 44 at a minimum the voltage drop across resistor R8 is so small that VT3 is either nonconductive (although on the verge of conducting) or passes a minute current. A small current flows between the ground line 39, through R7 and R8 and diode D3 to the point 44.

Precisely similar conditions prevail in the other half of the circuit and the potential of the point 45, connected to the collector of VT2, is substantially the same as that of point 44, so that a part of the small current through R7 and R8 flows through diode D4, both the diodes D3 and D4 being conductive.

Since VT3 is nonconductive or substantially so, no current, or only an insignificant current, flows through the winding 47, which is the control winding of the magnetic amplifier. Consequently there is full coupling between the primary and secondary windings of the magnetic amplifier, the maximum voltage is induced in the secondary winding and, the circuitry having been adjusted so that under this condition the motor 35 (FIG. 2) drives the carriage at the maximum desired speed, the line followers 5 and 6 proceed along the respective outline portions 16 and 23 at the maximum permitted speed, the cutters 11 and 12 (FIG. 1) making their cuts at this speed.

When the line follower 5 reaches the beginning of the flank 17 the resolver therein is rotated as the follower senses the change in direction of the outline, and it commands a low Y speed and a high X speed, so that the cutter may move in the new direction at its maximum permitted speed. The motor in the line follower begins to run to the left in FIG. 1 to apply the X movement. The Y signal in winding 37 is reduced and the current through R3 is correspondingly reduced, so that the capacitor C1 discharges to the new lower voltage level across R3. The time constant of C1 and R3 may conveniently be chosen to provide discharge of C1 from the full speed state to zero in one-quarter to one-half second.

The reduced base signal to VT1 causes a corresponding reduction in its collector current and the point 44 goes negative to a substantial extent. D3 follows point 44, so that the voltage applied to the resistor chain R7 and R8 increases and the current through these resistors increases in unison. The increased voltage drop across R8 drives the base of VT3 negatively and this transistor conducts heavily. The collector current of VT3, flowing through the control winding 47, reduces the output of the secondary winding of the magnetic amplifier so that the speed of carriage motor 35 (FIG. 3) is reduced to the speed required to drive the carriage at a low speed, which is correct for cutter 11 (FIG. 1).

When the point 44 is driven negative, as described above, the anode of D3 also goes negative, since the voltage drop in D3 is insignificant, so that the anode of D4, which is connected to the anode of D3, is negative with respect to its cathode. Consequently the diode D4 is biased off, i.e., it becomes nonconductive, so that the high speed signal still applied to the right-hand half of the circuit of FIG. 3 is ignored, that is to say, the Y speed is entirely controlled by the line follower 5, which commands the lower Y speed.

When the line follower 5 reaches the curve at the end of the flank 17 the X signal decreases and the Y signal increases until, at the outer extremity of this curve, the Y signal for an instant again reaches its maximum, after which it diminishes until, at the beginning of the flank 18, it is again reduced to a low speed signal. At the extremity of the curve between flanks 17 and 18 the X signal is reduced to zero, at the instant when the Y signal reaches its maximum, and thereafter the X signal which appears is of reversed phase, so that the line follower 5 begins to move in the opposite direction, that is to the right in FIG. 1 to follow the flank 18. The Y signal is not phase-reversed, and the circuit of FIG. 3 is in any case not phase-

responsive, so that the state of the left-hand half of the circuit of FIG. 3 is the same when following the flank 18 as when following the flank 17. During this period the cutter 12 is, of course, moving forward at a low speed, with the carriage, and cutting at that speed.

When the end of the flank 18 is reached the Y signal from line follower 5 increases to its maximum again, the conduction of VT1 increases to its previous high level, transistor TR3 becomes nonconducting, and the speed of the Y motor 35 is increased to its maximum, the line follower 5 following the portion 19 of its outline and the line follower 6 following the last part of the portion 24 of its outline.

When the line follower 6 senses the beginning of the flank 25 it produces an X signal commanding a high speed and its Y signal is reduced to low speed level. The conductivity of VT2 is now reduced, so that the current through R6 is reduced and the point 45 is driven negative. Transistor TR3 now conducts due to the current flowing through R8, R7, D4 and R6, D3 being biased off, so that the line follower 6 traverses flank 25, in the manner described in relation to line follower 5 and flank 17. The intervening curve and flank 26 are also traversed by the line follower 6 in the same way as the line follower 5 traversed the corresponding curve and flank 18. In the meantime the high speed signal in the left-hand half of the circuit is inhibited and the line follower with the 5 moves with the beam 3 at low speed along the straight part 19 of its outline.

When the line follower 5 reaches the beginning of the curve 20 its resolver delivers a gradually increasing X signal which causes the line follower to begin to move to the left in FIG. 1 and it delivers a gradually reducing Y signal. The action is as before, the Y motor being slowed down to the requirements of the line follower 5, the high speed signal from the line follower 6 being ignored since diode D4 is biased off. VT3 increases its conduction to the degree necessary to reduce the Y speed as required. When, however, line follower 6, having traversed the portion 27 of its outline, reaches the beginning of angled portion 28 its resolver produces a larger X signal. This is momentarily larger than the Y signal from the line follower 5, so that the Y speed is reduced to suit the line follower 6. A little later the point is reached at which the tangent to the curve 20 exceeds the angle of the portion 28 and the Y speed is further reduced to that commanded by the line follower 5. This condition continues while the line follower 6 completes the portion 28 and passes on to the portion 29. Shortly after this the line follower 5 passes on to the straight portion 21 and commands a maximum Y speed. Immediately the Y signal from the line follower 6 takes control and the Y speed is only allowed to rise to the level which it commands. In due course the line follower 5 reaches the transverse portion 22 and delivers a zero Y speed signal, i.e., no Y signal at all. This stops the carriage altogether while the line follower 5 moves at maximum speed to the right on the drawing. Meanwhile the cutter 12 is stationary. The radius 22 is very desirable since it ensures that when the line follower 5 reaches it, its Y signal grows gradually so that the carriage speed increases gradually. This enables the cutter 12 to take up its cut gradually. The two cuts are completed by both line followers traversing the remaining portions 23 and 30 at maximum speed.

From the foregoing description it will be evident that the work to be done is completed at maximum speed, since at all times at least one of the cutters is cutting at its maximum permitted speed. Therefore the productivity of the machine is 100 percent and the output is a maximum. This condition is sharply distinguished from those obtaining in respect of the known arrangements referred to earlier.

FIG. 4 shows how, by the use of the invention, it is possible to produce two workpieces simultaneously, the workpieces being of a type which would normally be produced by a single cutter. The shapes happen to be such that the two outlines may be laid out in interlocking relationship, so that material is saved, and four line followers and oxygen jet cutters are used, each following its own outline. There will be four resolver windings and each is provided with its own circuitry

equivalent to the resolver winding 37, resistor R1, potentiometer RV1, capacitor C1, resistor R3, transistor VT1, resistor R4 and diode D3, all the four diodes being connected to the point 46. The remainder of the circuitry is the same as shown in FIG. 3.

The shape of the workpiece on the left in FIG. 4 is complex, consisting on one side of a straight portion 49, a steeply angled portion 50, a further straight portion 51, a curved portion 52, another straight portion 53, a further steeply angled portion 54 and a final straight portion 55. On the other side it consists of a straight portion 56, a transverse portion 57 leading via a radius 57a to a straight portion 58, a steeply angled portion 59, a further straight portion 60, a further steeply angled portion 61, another straight portion 62, another steeply angled portion 63, still another straight portion 64, a final steeply angled portion 65 and a final straight portion 66. It is intended that the one piece be finally cut off along the dotted line 67 and the other piece, reference 69, be cut off along the dotted line 68. The two workpieces are of identical shape but the workpiece 69 has been turned through 180° with respect to the other.

When the four cutters begin their cuts they all initially travel along straight lines in the Y direction, so they all command maximum Y speed and the control circuitry provides that speed. As soon as the fourth or right-hand line follower reaches the steeply angled portion 70 it commands a reduction in speed, so it takes control. As soon as it reaches the end of the portion 70 and again commands maximum speed the third line follower reaches the steeply angled portion 71 and it commands a lower Y speed and takes control. When it reaches the end of the portion 70 the second line follower reaches the transverse portion 57 and it causes the carriage to stop the Y movement. After this portion has been completed and the radius 57a has been negotiated all four line followers command full Y speed and the carriage travels forward at that speed until the first line follower encounters the steeply angled portion 50, when it takes control and slows the Y speed by the appropriate amount. It is not deemed necessary to describe the remainder of the operation in detail, but if the outlines are followed it will be evident that whichever of the line followers encounters the most steeply angled portion of its outline at any given instant reduces the Y speed to suit its own requirements, and that the cutter associated with that line follower is cutting at its maximum permitted speed because the associated X movement is correspondingly high.

Since at all times one or other of the cutters is cutting at its maximum speed it will be evident that the machines is always operating at the maximum speed which is theoretically possible. It will also be evident that the two workpieces illustrated in FIG. 4 will be cut in considerably less time than it would take to cut one workpiece by means of a single cutter. The invention provides another advantage. When cutting with a single cutter the portion of the workpiece being cut is heated to a very high temperature locally and this region of elevated temperature moves around the workpiece as cutting proceeds. Consequently, when the workpiece cools down to room temperature it is found that a certain amount of distortion of the shape has occurred. By cutting opposite sides of the workpiece simultaneously this distortion is largely balanced out.

FIG. 5 shows circuitry equivalent to that of FIG. 3 for controlling the carriage speed by means of the X signals. A resolver winding 73, a resistor R9, a potentiometer RV3 having a slider 74, capacitor C3, resistor R11 and diode D5 are precisely equivalent to the similar parts in the circuit of FIG. 3 and are connected to transistor VT4 having collector resistor R12, precisely as in the case of the circuitry associated with VT1 in FIG. 3. Similarly, resolver winding 75, diode D6, resistor R10, potentiometer RV4 having slider 76, capacitor C4, resistor R13, and collector resistor R14 are associated with transistor VT5 in precisely the same manner as the equivalent components are connected with VT2 in FIG. 3. Two further diodes D7 and D8 are equivalent to diodes D3 and D4 in FIG. 3 but are connected with reversed polarity as compared with

FIG. 3. The difference is that two resistors R15 and R16 are connected as a voltage dividing chain between the cathodes of the diodes D7 and D8 and negative line 77, and the junction of these resistors is connected to the base of transistor VT6, which is of NPN type. The emitter of transistor VT6 is connected to the negative line 77 while the collector is connected to one end of the control winding 47, the other end of which is connected to ground line 79. The resolver windings 73 and 75 are, of course, the X signal windings and not the Y signal windings shown in FIG. 3.

Assuming that the left-hand and right-hand halves of the circuitry of FIG. 5 are respectively associated with line followers 5 and 6 of FIG. 1 then, in the initial part of the operation whilst the followers are following the respective portions 16 and 24 of their outlines at maximum speed, the X signal in each case is zero. Accordingly VT4, VT5 are nonconductive (or only pass a minute current) so that resistors 12 and 14 have a minimum voltage drop across them and points 80 and 81 are driven negative to the maximum extent. Resistors R15 and R16 are so chosen that under this condition transistor VT6 is nonconductive (or substantially nonconductive) and no current (or only a minute current) flows through the control winding 47.

As soon as the line follower 5 reaches the beginning of the flank 17 a large X signal appears in the winding 71 and VT4 is driven into heavy conduction so that the point 80 is driven very substantially positive. Current flows from the point 80 through D7 and resistors R15 and R16 to cause VT6 to conduct heavily, and a substantial current flows through the control winding 47 to cause the carriage motor 35 to slow down to the appropriate low speed. Since the cathodes of D7 and D8 are connected together the cathode of D8 is driven positive when D7 is driven positive, so that the cathode of D8 is positive with respect to its anode. D8 is accordingly biased off, and the right-hand half of the circuitry of FIG. 5 is ineffective. This state continues until both the blanks 17 and 18 have been negotiated by the line follower 5, whereupon both line followers deliver a zero X signal while the first part of the portion 19 of the outline 7 and the last part of the portion 24 of the outline 8 are being followed at maximum speed.

When the line follower 6 reaches the flank 25 a large X signal appears at the winding 75 so that transistor VT5 is made to conduct heavily, the point 81 is driven heavily positive and current passes through D8 to resistors R15 and R16 to cause VT6 to conduct heavily, and this passes through the control winding 47. The positive movement of D8 causes D7 to be biased off.

From the description of the operation of the circuitry of FIG. 5 in following the first parts of the outlines 7 and 8, its operation in following the remainder of the outlines 7 and 8 or (in the modified form) in following the outlines of FIG. 4 will be clear without further description.

It will be clear that the circuits of FIG. 3 and FIG. 5 may be used in conjunction with sine/cosine potentiometers instead of resolvers and that, having regard to the number of different kinds of electronic "building blocks" which are available, the circuits may be contrived with different kinds of components. Moreover, the circuits may be redesigned to use NPN where PNP transistors are used, and vice versa. All these variations are within the scope of the invention provided that they fulfill the requirements of the circuitry as laid down above. It will also be evident that circuitry based on the above teaching may be devised for a DC servodrive system for the carriage in place of the AC drive system shown and described.

In the systems described with reference to FIGS. 3 and 5 the line followers deliver AC X and Y signals having the sine/cosine relationship described. Instead of the half-wave rectifiers D₁, D₂ and D₃, D₆ full-wave rectifiers could be employed. Where the line followers are of the type delivering DC X and Y signals they will incorporate sine/cosine potentiometers or equivalent devices instead of the synchro resolvers described. In such cases the half-wave rectifiers D₁, D₂, D₃ and D₆ or the equivalent full-wave rectifiers may be omitted, and a

proportion of the DC Y or X signals applied directly to the transistors VT1 and VT2 or VT3 and VT4 of these circuits. Where, with either AC or DC input signals, the circuits of FIG. 3 or 5 are to provide power for a DC Y motor the armature of the Y motor may be connected in the collector circuit of VT3 or VT6 in place of the magnetic amplifier winding 47. It will be evident that the circuit of FIG. 5 would be used for a Y signal input and the circuit of FIG. 3 would be used for an X signal input.

Where the X signals are to be used for control, the circuit of FIG. 3 may be modified, instead of using the circuit of FIG. 5. The modification consists in placing identical resistors in the emitter circuits of VT1 and VT2, changing the values of R4 and R6 as appropriate, and connecting the cathodes of diodes D3 and D4 to the respective emitters of VT1 and VT2.

A magnetic amplifier, as shown in the circuits of FIGS. 3 and 5, may introduce some nonlinearity in response. Moreover, where the X signals are used the output should not be in strict inverse proportion to the X magnitude of the X signal, since at any given instant the magnitude of the X signal is not inversely proportional to the Y signal but is related thereto by a square law, as pointed out earlier. These errors, as well as errors due to temperature variations, may be corrected by including components having nonlinear characteristics, such as thermistors, for example, at strategic points in the circuits.

In the embodiments of the invention so far described it is necessary that the outlines being followed should always move generally forward. As has been shown, the invention is capable of dealing with an outline which has a portion which lies transversely of the Y direction. The prior art arrangement referred to in which the carriage moves at constant speed could not deal with an outline of this type at all, while the other prior art arrangement in which one line follower provides the Y signals could not deal with a pair of outlines in which the second outline (the one which does not provide the Y signals) has a transverse portion. As has been shown, the arrangement according to the invention is capable of following a pair of outlines either of which may have a transverse portion such as the portion 22 in FIG. 1.

It is, however, possible to provide a further feature by the use of the invention, and that is the ability to follow a series of outlines one or more of which includes a portion which requires a reverse cut to a limited extent, that is, a cut in a direction of which one component of movement is in the reverse direction to the forward Y movement. This is illustrated in the diagrammatic drawing of FIG. 6, representing an oxygen jet cutting machine modified according to the invention, and the circuit diagram of FIG. 7.

Referring initially to FIG. 6, the machine shown comprises a base 111 having rails, respectively 112 and 113, at opposite sides thereof. A primary carriage, generally indicated by reference 114, is adapted to run on the rails 112 and 113 in the Y direction. The primary carriage 114 comprises a beam consisting of a transverse portion 115, three portions, respectively 116, 117 and 118, forming three sides of a rectangle, a further transverse portion 119, three further portions respectively 120, 121 and 122, forming three sides of a further rectangle, and a final transverse portion 123. The parts 116, 118, 120 and 122 each carry a rail, respectively 124, 125, 126 and 127. The rails 124 and 125 carry a secondary carriage 128, while the rails 126 and 127 carry a secondary carriage 129.

A line follower 130 is mounted for X movement on the secondary carriage 128 and an oxygen jet flame cutter 131 is mounted on the secondary carriage 129, while a second line follower 132 is mounted for X movement on the transverse portion 119 of the beam and a second oxygen jet flame cutter 133 is mounted for X movement along the transverse portion 123 of the beam. The two secondary carriages 128 and 129 are arranged for backward or reversed Y movement with respect to the carriage 114 and they are arranged to be driven together.

The line follower 130 is interconnected with the cutter 131 so that both move together in the X direction, that is, along the transverse portions of the respective secondary carriages 128 and 129, and the line follower 132 is interconnected with the cutter 133 for simultaneous X movement along the respective portions 119 and 123 of the primary carriage.

A motor is provided to drive the primary carriage 114 in the forward Y direction (that is, downwardly in FIG. 6) and another motor is provided to drive the secondary carriages 128 and 129 in the reverse Y direction with respect to the primary carriage.

A workpiece 134 is supported on the right-hand side of the machine shown in FIG. 6 while a substrate 135, indicated in dotted lines, carries two outlines generally indicated by respective references 136 and 137.

Outline 136 comprises an initial straight longitudinal portion 138, a projection having two sloping sides, respectively 139 and 140, joined by a curve, a further sloping portion 141 which leads to a curved projection 142 blending into a curved portion 143 which requires a reverse Y movement of the carriage, a straight portion 144 leading from the curve 143 to another curved portion 145 from which a further reverse Y movement is required to reach another curved portion 146 from which a final straight portion 147 runs in the Y direction.

The outline 137 comprises a first straight Y portion 148 followed by a projection having two sloping portions 149 and 150 joined by a curve and leading into a final straight Y portion 151. As shown in FIG. 6, the line followers 130 and 132 have already proceeded for some distance along the respective straight portions 138 and 148 of their outlines, and the two flame cutters 131 and 133 have already completed corresponding portions 153 and 154 of their cuts.

FIG. 7 shows one form of circuitry which may be used in accordance with the invention. In certain respects it is very similar to, and is based upon, the circuitry of FIG. 3. This circuitry is basic to promote a ready understanding of the invention and it is to be understood that limiting resistors, protective rectifiers, nonlinear components, and additional amplifying or emitter follower stages, which might be desirable in particular applications, have been omitted.

Referring to FIG. 7, the circuitry comprises a resolver winding 155, which is the Y winding of the resolver in the line follower 130, and two resistors R17 and R18 are connected in series across the winding 155, the resistors being of equal value. A point B at the junction of resistors R17 and R18 is connected to a positive or ground line 156 leading to a positive power supply terminal 157. A point A, which is the junction of one end of R17 with one end of the winding 155, is connected to the cathode of a silicon or other controllable rectifier SCR1, while the anode of SCR1 is connected to one side of a capacitor C5 and to one end of a resistor R19 as well as to the base of a PNP transistor VT7. The other side of capacitor C5 and the other end of resistor R19 are both connected to the ground line 156.

A point C, which is the junction of resistor R18 with the other end of winding 155, is connected to the cathode of another silicon or other controllable rectifier SCR2 whose anode is connected to one side of a capacitor C6, to one end of a resistor R20 and to the base of a PNP transistor VT8. The other side of capacitor C6 and the other end of resistor R20 are connected to the ground line 156.

The emitter of VT7 is connected to the ground line and the collector of this transistor is connected to one end of a resistor R21 having its other end connected to a negative supply terminal 158a. The collector of VT1 is also connected to the cathode of a diode D9.

The Y resolver winding 159 of the line follower 132 has two resistors, respectively R22 and R23, of identical value with the resistors R17 and R19, connected in series across it, the junction of R22 and R23 being connected to the ground line 156. It will be noted that the remaining circuitry is all connected across the resistor R22, and the object of having R23 is only to provide load conditions for the winding 159 equivalent to those of the winding 155.

The junction of R22 and one end of the winding 159 is connected to the cathode of a diode D10 whose anode is connected to one side of a capacitor C7, to one end of a resistor R24, and also to the base of a PNP transistor VT9. The other side of capacitor C7 and the other end of resistor R24 are connected to the ground line 156.

The emitter of VT9 is connected to the ground line 156 while the collector of this transistor is connected to one end of a resistor R25 which has its other end connected to the negative supply terminal 158a. The collector of VT9 is also connected to the cathode of a diode D11 and the anodes of diodes D9 and D11 are connected together.

Two resistors R26 and R27 are connected in series between the junction of diodes D9 and D11 and the ground line 156 and the junction of R26 and R27 is connected to the base of a further PNP transistor VT10. The emitter of VT10 is connected to the ground line 156 and the collector of this transistor is connected to one end of a control winding 159 which has its other end connected to the negative line 158. The winding 159 is the control winding of a magnetic amplifier equivalent to the winding 47 of FIGS. 3 and 5. There is preferably a potentiometer connected to the output winding of the magnetic amplifier, the slider being connected to the input of the electronic amplifier so that the maximum speed of the carriage 114 (when no current flows in the control winding 159) may be adjusted.

The emitter of transistor VT8 is connected to the ground line 156 while the collector of this transistor is connected to one end of a resistor R28 which has its other end connected to a negative supply terminal 158b, which is the same as terminal 158a but is shown in two different positions in FIG. 7 to avoid complicating the diagram. Connected between the collector of VT8 and ground line 156 are two resistors R29 and R30 in series, the junction of R29 and R30 being connected to the base of another PNP transistor VT11 having its emitter connected to the ground line 156 and having its collector connected to one end of a control winding 160, the other end of which is connected to the negative supply terminal 158b. The control winding 160 is on a second magnetic amplifier which controls the AC voltage applied to a further electronic amplifier which feeds a secondary carriage motor which drives the two secondary carriages 128 and 129 of FIG. 6.

Reverting to FIG. 7, a secondary winding 161 of a transformer has one end connected to the ground line 156 and its other end connected to the gate electrodes of the two silicon controlled rectifiers SCR1 and SCR2. A resistor R31 is connected in parallel with the winding 161. The transformer having the secondary winding 161 is fed from the same supply as the resolver having the Y winding 155 and it is arranged that when the Y signal provided by the line follower 130 commands a forward carriage movement the alternating Y signal appearing in the winding 155 is in phase with the voltage induced in the winding 161, that is to say, during a half-cycle in which point A is positive with respect to point C, point D is positive with respect to point E. However, when the line follower 130 commands a backward carriage movement its output signal is reversed in phase so that the signal in the winding 155 and the voltage in the winding 161 are in phase opposition.

At the commencement of a cutting operation the secondary carriages 128 and 129 are in their most forward positions on the primary carriage 114, as shown in FIG. 6. When the cutting operation begins, both the line followers deliver maximum speed Y signals and zero X signals since both the initial portions 138 and 148 of the outlines are straight and lie in the Y direction.

The voltage appearing in the winding 155 is applied to the two resistors R17 and R18. During each half-cycle when the point A is positive with respect to point B and point B is positive with respect to point C, point D is positive with respect to point E. The positive potential at point A is applied to the cathode of SCR1 while the potential at point B, which is negative with respect to point A, is communicated through R19 to the anode of SCR1, so that the cathode of SCR1 is negative

with respect to its anode and it will not conduct whatever the potential at its gate. The potential at the point B, which is positive with respect to that at point C, is applied through R20 to the anode of SCR2 and since the cathode of this rectifier is connected to the negative end of R18 SCR2 will conduct if its gate is made positive with respect to its cathode. However, the point D is connected to point B and the point E, which is connected to the gate of SCR2, is negative with respect to the point D, therefore SCR2 is also prevented from conducting. It is arranged that the voltage across R31 is higher than the maximum voltage which can appear across R17 or R18.

In the other half-cycles of the alternating signal, point C is positive with respect to point B and point B is positive with respect to point A, while point E is positive with respect to point D, which is connected to point B. During these half-cycles the potential of point C is applied to the cathode of SCR2 while the potential of point B is applied through R20 to the anode of SCR2. Therefore, the anode of SCR2 is negative with respect to its cathode and SCR2 will not conduct whatever potential may be applied to its gate. The potential of point B is communicated through R18 to the anode of SCR1 and since the cathode of SCR1 is connected to the point A, which is negative with respect to point B, SCR1 will conduct provided that its gate electrode is made positive with respect to its cathode. Since the gate electrode of SCR1 is connected to the point E, which is positive with respect to point D and point B, SCR1 conducts during this half-cycle. Therefore, while the line follower 130 is commanding a forward carriage movement SCR1 conducts during alternate half-cycles and current flows through R19. The voltage drop across R19 is stored in capacitor C5 and the base of VT7 is driven negative by the voltage drop in R19. Since the line follower 130 is commanding a maximum Y speed, the signal in winding 155 is a maximum and this causes VT1 to conduct heavily so that there is a large voltage drop across resistor R21 and the collector of VT7 is at a potential very close to that of the ground line 156. The two resistors R26 and R27 have their values so selected that when the collector of VT7 is at a potential close to that of the ground line 156 the voltage drop across the resistor R27 is so small that the base of VT10 is not sufficiently negative with respect to its emitter to enable VT10 to conduct to any appreciable extent. Accordingly, there is no current, or at best only a minute current, through the control winding 159, the associated magnetic amplifier operates as an ordinary transformer, and the primary Y carriage motor is driven at maximum speed. This motor is so connected that it can only drive the primary carriage forwards.

The winding 159 also produces a maximum Y speed voltage and on alternate half-cycles the diode D10 conducts so that current flows from the junction of R22 and R23 through R24 and back to the outer end of the winding 159. The voltage drop in R24 drives the base of VT9 negative to cause it to conduct as heavily as VT7 and this base potential is stored in C7. Accordingly there is a heavy voltage drop in R25 and the collector of VT9 is substantially at the same potential as the collector of VT7. Assuming that the characteristics of all similar components are truly identical, the small current which flows from R27 and R26 divides, so that one-half of it flows through D9 and R21 while the other half flows through D11 and R25. It will be recognized that, apart from the pairs of voltage dividing resistors connected across the resolver windings and the use of the silicon controlled rectifier associated with VT7, the operation of the circuitry so far described is identical with the operation of the circuitry of FIG. 3.

From the description given above it will be clear that during the period when the line follower is delivering a forward Y signal and SCR1 is conducting during alternate half-cycles, SCR2 is nonconductive on both half-cycles of the signal in the winding 155. Accordingly the base of VT8 is substantially at the same potential as its emitter, and VT8 is nonconductive. Only the current which flows through R30 and R29 flows through R28, so that the potential of the collector of VT8 is near that of the negative terminal 158b. Under this condition

the voltage drop across R30 is sufficient to cause VT11 to conduct very heavily, and a heavy current flows through the control winding 160. This saturates the core of the associated magnetic amplifier, so that it delivers no output to the associated electronic amplifier and no driving voltage is applied to the driving motor for the secondary carriages, which therefore remain at rest. The driving motor for the secondary carriages is so connected that it can only drive these carriages in the reverse direction.

While both line followers are commanding a forward Y movement it will be evident that the circuitry of FIG. 7 operates in the same way as that of FIG. 3, and there is no need to describe in detail how it operates while the line followers are negotiating the portions 136 and 137, the steeply angled flanks 149, 150 and 139, 140, or the initial part of the portion 151 and the angled portion 141.

At the end of the slope 141 the line follower 138 again reaches a part of the outline which is parallel to the Y direction and the carriage speed momentarily rises to a maximum, until the curved portion 142 is reached. The line follower negotiates this curve and the Y speed is progressively reduced until it reaches zero at the lowermost point of this curve. After this point the curve 142 begins to lead in the reverse direction, that is, the component of the curve which is parallel to the Y ordinate is in a direction opposite to the forward Y direction. Accordingly the Y signal which appears at the winding 55 is of reversed phase with respect to the Y signals which were being delivered previously.

Under these conditions, during half-cycles when the point A is positive with respect to point B and point B is positive with respect to point C, the point D is negative with respect to point E. During these half-cycles the cathode of SCR1, which is connected to point A, is positive with respect to its anode, which is connected through R19 with point B, and so SCR1 cannot conduct, irrespective of the potential at its gate. Point B is positive with respect to point C and the potential at point B is applied through R20 to the anode of SCR2 whose cathode is connected to point C. SCR2 is therefore in a condition to conduct and since point E is positive with respect to point B, which in turn is positive with respect to point C, SCR2 conducts during these half-cycles. When point C is positive with respect to point B and point B is positive with respect to point A, point D is positive with respect to point E. Under these conditions SCR2 cannot conduct because its cathode is positive with respect to its anode and SCR1 cannot conduct because its gate is negative with respect to its cathode. Accordingly VT7 receives no signal at all during either half-cycle and it is cut off. Consequently the voltage drop in R21 is only that due to the current through R27 and R26 and D9 and the collector of VT7 goes negative to a maximum extent. This automatically biases D11 off, VT10 conducts to its maximum extent, the heavy current through the control winding 159 saturates the core of the first magnetic amplifier so that its output is reduced to zero, and the primary carriage motor stops. On the other hand, the half-cycles of the signal during which SCR2 conducts causes half-cycles of current to pass through R20, the voltage drop in which is communicated to C6 and stored there, so that VT8 begins to conduct. The collector of VT8 is driven positive so that the current through R30 and R29 is reduced and the conduction of VT11 is reduced. This in turn reduces the current through the control winding 160, with the result that the second magnetic amplifier produces an output which is substantially proportional to the signal applied to VT8, and the secondary carriages 128 and 129 begin to move backwards to enable the line follower 130 to follow the reverse or reentrant portion of the curves 142 and 143. When the line follower 130 has passed the uppermost portion of the curve 143 it commands a forward Y signal, so that the phase of the signal in winding 155 again reverses, whereby VT8 is cut off, thus stopping the secondary carriages. The forward Y signal again causes SCR1 to conduct and the primary carriage begins to move forward while the line follower 130 follows the second part of the curve 143. The straight portion 144 is

negotiated with the primary carriage moving at maximum speed, and the carriage progressively slows down while the first part of curve 145 is being followed.

As soon as the line follower passes the lowermost portion of the curve 145 the phase of the signal in the winding 155 is again reversed, so that the primary carriage is stopped while the backward movement along the second part of the curve 145 and the first part of the curve 146 is carried out by the secondary carriages 128 and 129.

As soon as the uppermost portion of the curve 146 has been passed the phase of the Y signal is once again reversed, so that the remainder of curve 146 and the straight portion 147 are traversed with the primary carriage moving forward.

It will be evident that the line follower 138 will reach the end of the portion 151 of its outline before the line follower 130 reaches the end of the portion 147, the gain being the amount by which the secondary carriages 128 and 129 have been moved in the backward direction. This is normally no disadvantage but if desired it is possible to arrange for the secondary carriages to be capable of forward as well as backward movement. A switch may be incorporated in the carriage 128 which is changed over as soon as the carriage moves backward from its most forward position and this switch is arranged to switch the circuitry in such a way that after the secondary carriage 128 has made a backward movement the next forward movement signal from the line follower 130 is also applied to the secondary carriage 128 which then moves forward until the previously executed backward movement has been made up and the carriage 128 returns to its most forward position, when the said switch is changed back. The changing back of this switch transfers the forward carriage movement signal back to the primary carriage.

From the foregoing description it will be clear that the arrangement according to the invention has the same feature as the arrangement described in relation to FIGS. 1 to 5 in that, at any instant, at least one of the cutters is traveling at its maximum speed and therefore the cutting of the two outlines, whatever their nature, is completed in the shortest possible time, thereby producing maximum productivity from the machine. The arrangement according to FIGS. 6 and 7 has the additional feature that one of the outlines may involve a reversed cut. However, the invention may be further extended, in that four secondary carriages may be provided so that both line followers and both cutters are able to move backwards. The circuitry of FIG. 7 would require the addition of another transistor and silicon controlled rectifier, so that the right-hand portion of the circuitry duplicates the left-hand portion. The two diodes would have to be connected respectively to the collector of VT8 and the collector of the additional transistor. In that case, whichever one of the line followers wishes to follow a reversed part of its outline would cause the primary carriage and the other line follower to be stopped.

When the primary carriage is stopped because one line follower is following a reversed portion of its outline, the stopped cutter will tend to cut a hole in its workpiece a little larger than the width of its normal cut and will then "lose" its cut. Once the cut is "lost" special steps have to be taken to reestablish it, in that the flame must be brought very slowly towards the edge to be cut and held there for a short period until the metal at the edge is heated sufficiently to restart the chemical reaction which takes place during flame cutting. A radius in the outline will assist, as mentioned earlier, but the invention also envisages that when the Y signal changes to a reverse signal the main carriage should not be entirely stopped but should be allowed to continue to move forward at a very low speed, a fraction of the maximum cutting speed. Under these conditions the line follower which is following the complex reversed portion of its outline will still faithfully follow the outline and will reproduce it correctly. The maximum backward Y speed may be modified. For example, if the maximum cutting speed of the cutters is a nominal 10 units of speed the maximum forward speed of the primary carriage

might be set at 10 and the minimum speed might be set at 0.5, and to ensure that the maximum cutting speed may be achieved when moving backwards the maximum backward speed of the secondary carriages could be set at 10.5, to give a net backward cutting speed of 10.

As in the arrangements described in relation to FIGS. 1 to 5, the arrangement of FIGS. 6 and 7 is not limited to two line followers and two cutters, and a larger number may be used if desired, and one or any number of the line followers may be mounted on secondary carriages, enabling them to move backwards.

I claim:

1. A method of simultaneously following a number of outlines which may deviate individually and irregularly from a longitudinal direction comprising the steps of guiding a separate line follower over each outline, continuously deriving electrical longitudinal movement and transverse movement signals from each line follower depending upon the instantaneous direction of the respective outline, continuously comparing signals from all the line followers, continuously selecting that signal which at the instant of selection corresponds to the lowest longitudinal speed, driving all the line followers in the longitudinal direction at identical speeds, and continuously varying the said identical speeds in dependence upon the magnitude of the selected signal.

2. A method as claimed in claim 1 comprising the step of selecting the longitudinal movement signal which has the lowest magnitude, and driving the line followers at a speed directly related to the said magnitude.

3. A method as claimed in claim 1 comprising selecting the transverse movement signal having the highest magnitude, and driving the line followers at a speed related by an inverse function to the said magnitude.

4. Apparatus for simultaneously following a plurality of outlines for the purpose of guiding separate tools comprising a carriage bearing a plurality of photoelectric line followers each adapted to follow a separate outline and deliver movement signals, means for mounting the line followers so that they travel simultaneously in a longitudinal direction while allowing each line follower to make independent transverse movements to follow the respective outline, means to receive movement signals from all the line followers and to compare the movement signals continuously, means for continuously selecting whichever movement signal corresponds to the slowest longitudinal movement, and means to vary the longitudinal speed of the carriage continuously in dependence upon the magnitude of the selected movement signal.

5. Apparatus as claimed in claim 4 in which the signals are all longitudinal movement signals, the signal selecting means being responsive to the signal of smallest magnitude.

6. Apparatus as claimed in claim 4 in which the signals are all transverse movement signals, the signal selecting means being responsive to the signal of largest magnitude, the means to control the speed of the line followers comprising means to control the longitudinal speed according to an inverse function of the selected signal.

7. Apparatus as claimed in claim 4 in which the movement signals are electrical signals, comprising electronic means to compare the magnitudes of the movement signals in order to select the signal corresponding to the slowest longitudinal

movement.

8. Apparatus as claimed in claim 7 comprising a transistor circuit for each signal, the signal being applied to the respective transistor base, diode means in the collector circuit of each transistor, all the diode means being connected together so that at any instant all the diode means except that associated with the selected signal are reverse biased.

9. A method of simultaneously following a number of outlines over which separate line followers are to be guided for the purpose of guiding separate tools, comprising the steps of deriving longitudinal and transverse movement signals depending upon the instantaneous direction of each outline being followed, comparing the signals and selecting a signal which corresponds to the lowest longitudinal speed, driving all the line followers in the longitudinal direction at a speed related to the magnitude of the selected signal, detecting a reverse longitudinal movement signal, stopping the longitudinal forward movement of all the line followers, driving the line follower which delivered the reverse movement signal in the reverse longitudinal direction until the reverse movement signal ceases, and then continuing the forward longitudinal movement of all the line followers.

10. A method as claimed in claim 9 comprising the step of detecting the reverse longitudinal movement signal by its changed phase with respect to the phase of the forward movement signals.

11. Apparatus for simultaneously following a plurality of outlines for the purpose of guiding separate tools comprising a primary carriage capable of longitudinal movement, at least one secondary carriage capable of forward movement with and reverse movement with respect to the primary carriage, at least one photoelectric line follower capable of delivering movement signals mounted on the primary carriage for movement therewith, an additional photoelectric line follower capable of delivering movement signals mounted on the secondary carriage, means included in the mountings of all the line followers to enable each line follower to make independent transverse movements in order to follow the respective outline, means to cause the primary and secondary carriages to move forward simultaneously while all the line followers are producing forward longitudinal movement signals, means to detect the production of a reverse movement signal by the said additional line follower, means responsive to the reverse movement signal to stop the forward movement of the primary carriage while the secondary carriage performs the reverse movement, and means to restart the forward movement of the primary and secondary carriages when the said additional line follower again produces a forward movement signal.

12. Apparatus as claimed in claim 11 comprising means to compare the magnitudes of the movement signals and to select the movement signal corresponding to the slowest forward movement, and means to drive the primary and secondary carriages forward at a speed dependent upon the magnitude of the selected signal.

13. A modification of the apparatus claimed in claim 11, in which the means responsive to the reverse movement signal causes the speed of forward movement of the primary carriage to be reduced to a low level while the secondary carriage performs the reverse movement.