[11] 3,586,184

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[54] CONTROL APPARATUS AND METHOD FOR AN EXCAVATING SHOVEL
15 Claims, 4 Drawing Figs.

[52] U.S. Cl. 214/136, 214/1
[51] Int. Cl. B66c 1/00, B66c 13/14
[50] Field of Search 214/135, 136, 137, 132

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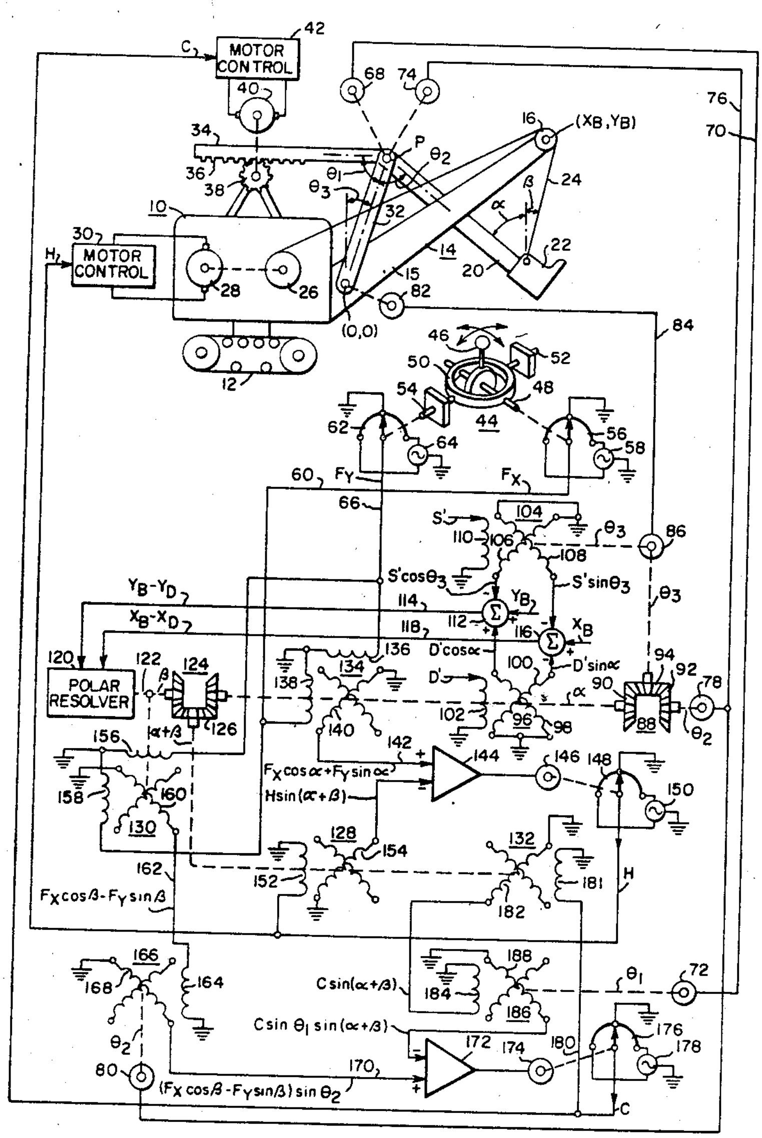
ABSTRACT: Described is a control system and method for controlling a powered excavating shovel of the type having a boom extending from a main frame, and in which a digging bucket is carried at the lower end of a dipper stick reciprocable transversely of the boom and pivotable relative to the main frame about an axis at right angles to the transverse movement paths. More specifically, the invention described herein relates to a control system in which signals representing desired horizontal and vertical forces for the digging bucket are obtained from a single two-axis master switch and translated into signals for controlling the application to the bucket of components of said forces through and in line with the dipper stick and through and in line with a hoist cable secured to the bucket and passing over a pulley at the outer end of the boom.



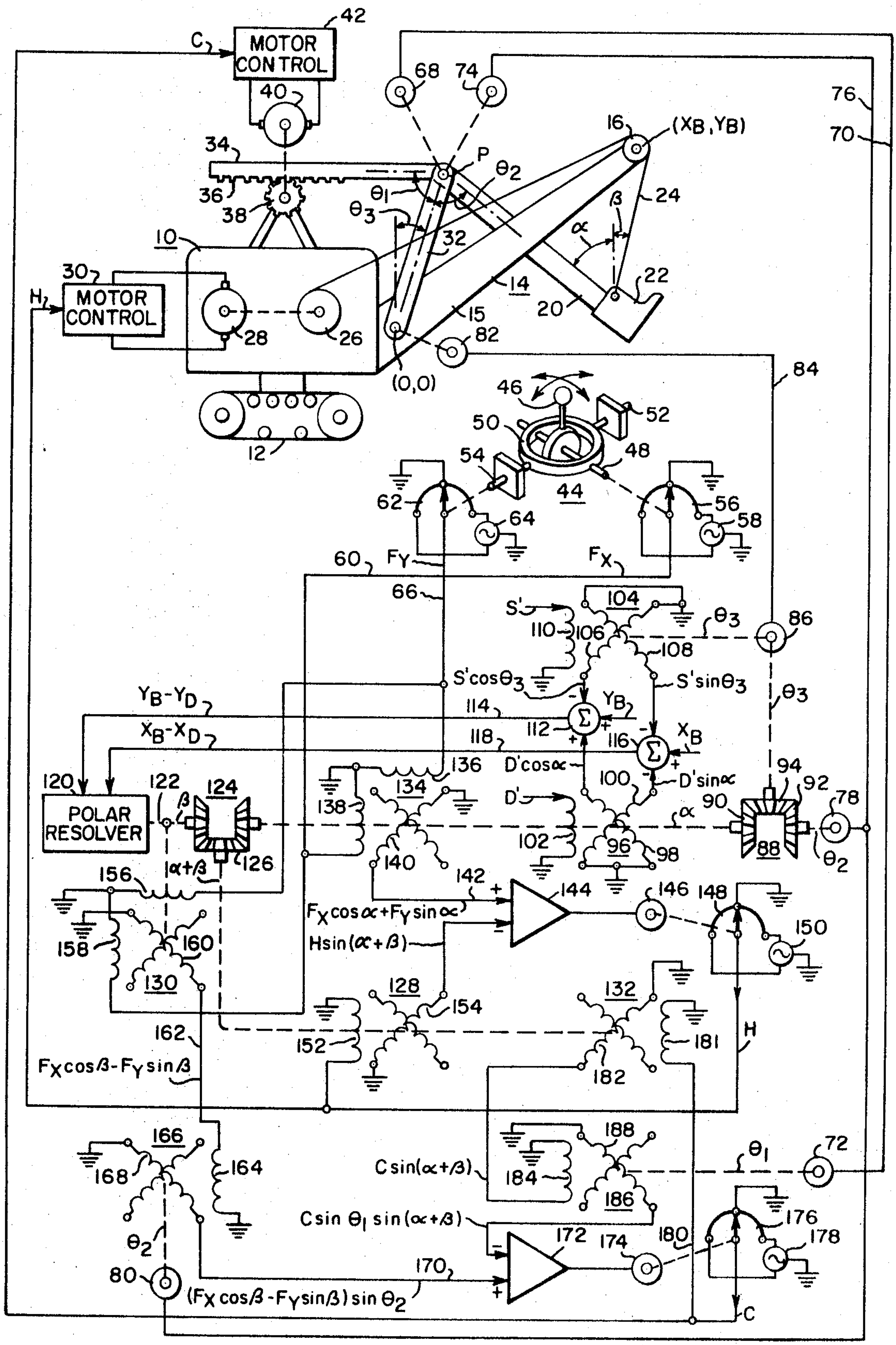

MOTOR CONTROL
MOTOR CONTROL
POLAR RESOLVER
F_Y
F_X
$S'\cos\theta_3$
$S'\sin\theta_3$
Y_B-Y_D
X_B-X_D
$D'\cos\alpha$
$D'\sin\alpha$
$F_X\cos\alpha+F_Y\sin\alpha$
$H\sin(\alpha+\beta)$
$F_X\cos\beta-F_Y\sin\beta$
$C\sin(\alpha+\beta)$
$C\sin\theta_1\sin(\alpha+\beta)$
$(F_X\cos\beta-F_Y\sin\beta)\sin\theta_2$
(X_B,Y_B)
$(0,0)$

FIG. 1.

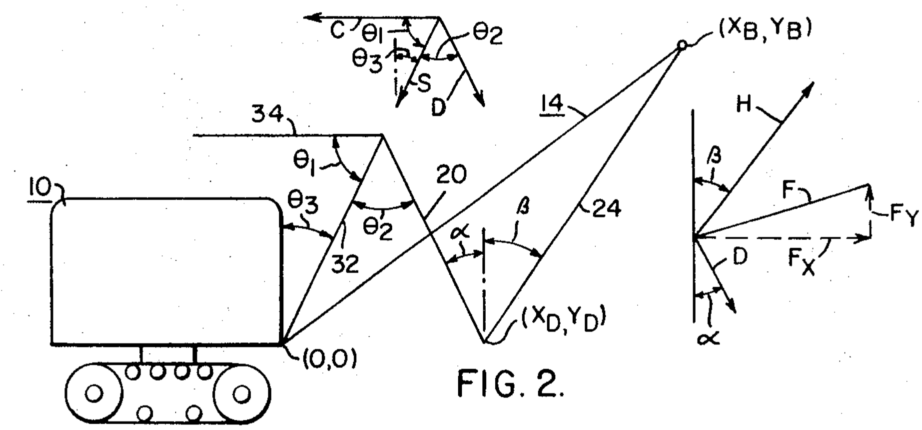


FIG. 2.

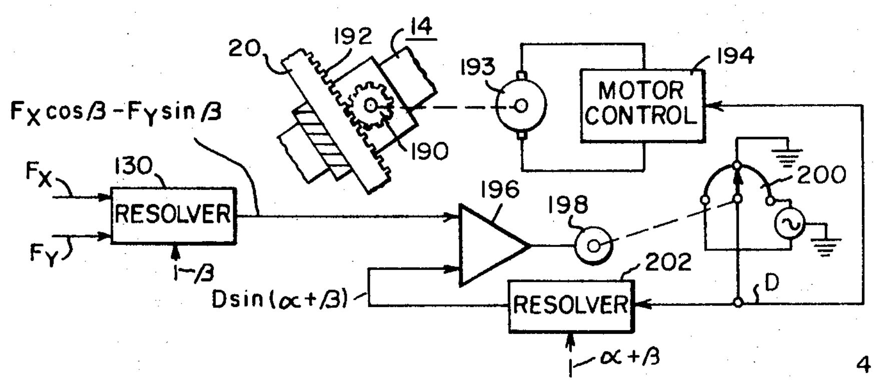


FIG. 3.

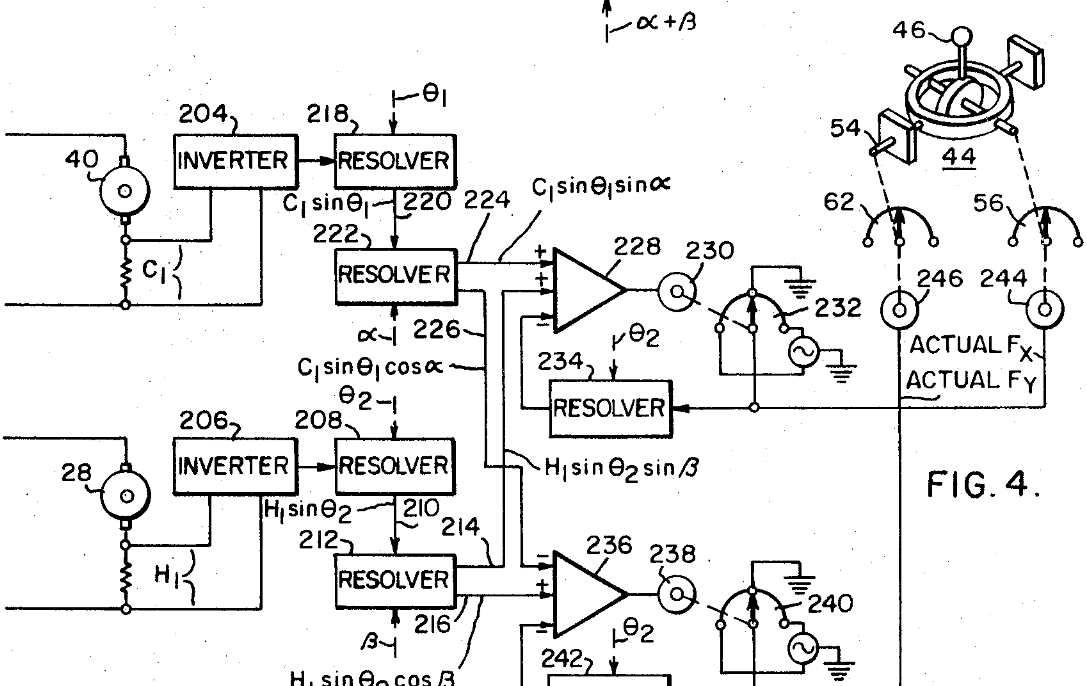


FIG. 4.

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CONTROL APPARATUS AND METHOD FOR AN EXCAVATING SHOVEL

BACKGROUND OF THE INVENTION

Conventional control systems for such excavating shovels provide separate controlling levers for the hoist, the swing, and the crowd motion of the shovel. The separate control components must be added vectorially by the operator by continually varying the positions of three separate master levers.

With reference to the dipper stick, a swing force that causes the dipper to move to the left or right is usually controlled by the feet of the operator. A crowd motion, causing the dipper to move either forward or away from a bank of material which is being dug, is controlled by the back or forward movement of one hand of the operator. The hoist motion causes the dipper to move up or down through an arc, as controlled by the back or forward movement of the other hand of the operator. With such a conventional arrangement, the shovel operator must vectorially add the separate required hoist, swing and crowd control components in order to, for example, move the dipper in a straight line from a dump position back to a point to continue digging.

It is readily apparent that an acute sense is necessary to coordinate the hoist, swing and crowd control components so that no time will be lost in the dipper travel from one position to another. Since the coordinating ability of shovel operators may vary greatly, the difference in the work output for a given shovel will also vary greatly.

When such shovels are powered by means of direct current electrical motors, speed or voltage regulators with current limit are ordinarily employed. With such a control, the operator is able to rely on a given constant speed for a specific position of a controller master switch. When digging in the bank, however, the machinery is forced to operate on the slope of the volt-ampere curve so that for a given master switch position, the restraining effort exerted by the material in the bank will have a direct effect on the speed of the dipper. Thus, the dipper speed, when digging, which is a combination of hoisting and crowding, is not governed solely by the controller setting. The operator is required to constantly change the hoist and crowd controlling switches with relation to each other to follow the digging path desired and to counteract for changing resistive loads while going through the bank. Needless to say, the problem of coordination is quite complex.

SUMMARY OF THE INVENTION

As an overall object, the present invention seeks to provide a new and improved system and method for operating an excavating shovel, which system and method eliminate much of the physical coordination and skill required of the operator by prior art control systems for such equipment.

More specifically, an object of the invention is to provide a control for dipper stick-type excavating shovel in which the horizontal and vertical force signals for the digging bucket are derived from a single two-axis master switch. In this manner, instead of manipulating two levers as in prior art control systems, the operator simply has a single lever which he can move toward and away from himself and also up or down.

Another object of the invention is to provide a control system of the type described above in which movement of the two-axis control lever produces signals which are proportional to the desired force components of the digging bucket. In this manner, the further the operator moves the control lever from its central or null position, the greater will be the force applied to the bucket in the desired direction.

Still another object of the invention is to provide a single two-axis master switch control arrangement of the type described above in which resistive torques proportional to actual forces in the X and Y direction on the digging bucket are imposed on the master switch. This permits the operator to "feel" a restraint against any master switch movement in proportion to the drive motor outputs for each motion.

In accordance with the invention, there is provided a single two-axis master switch or controller movable in a first direction and in a second direction at right angles to the first direction for controlling the vertical and horizontal forces imparted to the digging bucket, respectively. Means are provided for producing a first electrical signal which varies as a function of the position of the controller along said first direction, further means are provided for producing a second electrical signal which varies as a function of the position of the controller along the second direction, and circuitry is connected to the switch and responsive to the first and second signals for controlling the crowd and hoist forces imparted to the shovel.

Further, in accordance with the invention, the current (proportional to torque) through the drive motors is sensed and utilized to generate signals which are fed to torque motors on the two-axis master controller to develop counteracting restraining forces on the controller proportional to the forces imparted on the digging bucket. Thus, if the bucket is moving through loose material in a bank, for example, and very little restraining force is encountered, the operator can "feel" this by virtue of the fact that very little restraining force will be imparted to the control handle. On the other hand, if the digging bucket encounters great resistance, the operator will "feel" this by virtue of a greater restraining force on the handle.

The above and other objects and features of the invention will become apparent from the following detailed description taken in connection with the accompanying drawings which form a part of this specification, and in which:

FIG. 1 is a schematic diagram of one embodiment of the invention as applied to a knee-action power shovel having a stiff leg and crowd handle;

FIG. 2 is a line diagram of the trigonometric relationships between the various components of the shovel shown in FIG. 1, together with force diagrams showing the forces imparted on various components of the shovel of FIG. 1;

FIG. 3 is a partial schematic diagram illustrating an alternative embodiment of the invention wherein the dipper stick of the shovel is actuated directly rather than through a stiff leg-crowd handle arrangement; and

FIG. 4 comprises a block diagram of circuitry necessary to produce resistive forces on the two-axis master switch of FIG. 1 proportional to the forces exerted on the digging bucket in the X and Y directions.

With reference now to the drawings, and particularly to FIG. 1, the power shovel schematically shown includes a main frame **10** mounted on cats **12**; however the shovel could also be mounted on shoes or, for that matter, be permanently positioned. Extending outwardly from the main frame **10** is a main boom **14** which carries, at its outer extremity, a sheave **16**. The boom **14** is formed from two identical laterally spaced elongate members, only one of which, member **15**, is visible in the drawing, and which members form a guideway for a dipper stick **20** slidably disposed in the space between these members and constrained to move within the generally vertical plane in which the longitudinal axis of the boom lies. The dipper stick **20** carries, at its lower end, a digging bucket **22**; while bucket **22** is connected to cable **24** which passes around sheave **16** to a winch or drum **26** on the main frame **10** driven by means of motor **28**. The motor **28**, in turn, is controlled by motor control circuitry **30** which may be of any conventional type.

Pivotally connected to the upper end of the dipper stick **20** at a pivot point P is a stiff leg **32** which, at its lower end, is pivotally connected to the main frame **10** at the base of boom **14** such that the leg **32** can rotate about an axis identified as **0,0**. The upper end of the stiff leg **32** and the dipper stick **20** are also pivotally connected at pivot point P to a generally horizontally extending crowd handle **34** provided with a rack **36** which engages a gear **38**. Gear **38**, in turn, is driven by means of a motor **40** controlled by motor control circuit **42**.

In the operation of the shovel shown in FIG. 1, rotation of the winch **26** by motor **28** will cause the bucket **22** to swing through an arc about the pivotal connection P. Rotation of the gear **38**, on the other hand, will cause the dipper stick **20** to move transversely of the boom, while the stiff leg **32** rotates through an arc about the axis **0,0**. As will be understood, a combination of movements of the crowd handle **34** and drum **26** will be required to manipulate the digging bucket **22** in the desired manner.

The spatial relationship of the various elements of the shovel of FIG. **1** are shown in FIG. **2**. The position of the axis of sheave **16** is fixed and identified as point (X_B, Y_B); while the position of the digging bucket is identified as point (X_D, Y_D). This position, of course, will vary. The connection of the boom **14** and crowd handle **32** to the frame **10** is again identified by the point **(0,0)**. The angle between the crowd handle **34** and stiff leg **32** is identified as θ_1; the angle between dipper stick **20** and stiff leg **32** is identified as θ_2; and the angle between the stiff leg **32** and vertical is identified as θ_3. The angle between the hoist cable **24** and vertical is identified as the angle β; while the angle between vertical and the dipper stick **20** is identified as α. The forces imparted by the hoist cable **24** and the dipper stick **20** are identified as H and D, respectively, the resultant or total force on the digging bucket **22** being identified as F. This force F, in turn, can be resolved into its X and Y components identified as F_X and F_Y. These are the forces which must be determined by the operator in moving a single two-axis master switch, hereinafter described, in the X (horizontal) or Y (vertical) direction. Similarly, the force on the crowd handle and that on the stiff leg are identified as C and S, respectively.

In the force diagram of FIG. **2**, it can be seen that the following trigonometric relationship exist:

1. $F_X=D \sin\alpha+H \sin\beta$;
2. $F_Y=-D \cos\alpha+H \cos\beta$; and
3. $C \sin\theta_1=AHD \sin\theta_2$

If we multiply Equations (1) and (2) above by $\cos\alpha$ and $\sin\alpha$, respectively, the following equations result:

4. $F_X \cos\alpha=D \sin\alpha \cos\alpha+H \sin\beta \cos\alpha$
5. $F_Y \sin\alpha=-D \cos\alpha \sin\alpha+H \cos\beta \sin\alpha$

By adding Equations (4) and (5) above, the following equation results:

6. $F_X \cos\alpha+FAYY \sin\alpha=H (\sin\beta \cos\alpha+\cos\beta\sin\alpha)$ or
7. $F_X \cos\alpha+FAYY \sin\alpha=H \sin(\alpha+\beta)$.

Similarly, Equations (1) and (2) above can be multiplied by $\cos\beta$ and $\sin\beta$, respectively, to derive the following:

8. $F_X \cos\beta=D \sin\alpha \cos\beta+H \sin\beta \cos\beta$; and
9. $F_Y \sin\beta=-D \cos\alpha \sin\beta+H \cos\beta \sin\beta$.

Subtracting Equation (9) from equation (8) results in:

10. $F_X \cos\beta-FAYY \sin\beta=D (\sin\alpha \cos\beta+\cos\alpha \sin\beta)$ or
11. $F_X \cos\beta-FAYY \sin\beta=D \sin (\alpha+\beta)$.

From Equation (3) above, however, it can be seen that:

12. $D=C \sin\theta_1/\sin\theta_2$.

Substituting for D in Equation (11) above results in:

13. $(F_X \cos\beta-FAYY \sin\beta) \sin\theta_2\, c \sin\theta_1 \sin(\alpha+\beta)$

In an electrical servocontrol system wherein electrical signals from a single master controller proportional to desired F_X and desired F_Y must be balanced against electrical signals proportional to the forces H and C to produce a zero or null output; Equations (7) and (13) above may be rewritten as follows:

14. $F_X \cos\alpha+FAYY \sin\alpha-H \sin(\alpha+\beta)=0$ and
15. $(F_X \cos\beta-F_Y \sin\beta) \sin\theta_2-C \sin\theta_1 \sin(\alpha+\beta)=0$.

Thus, by developing signals proportional to the desired force on the bucket along the X-axis (i.e., F_X) and along the Y-axis (i.e., F_Y), signals proportional to desired H and desired C for driving motors **26** and **40** can be derived, assuming that the angles α, β, θ_1 and θ_2 can be derived.

Circuitry for accomplishing the foregoing is shown in FIG. **1** and includes a two-axis master switch or controller, under the control of the operator, and identified generally by the reference numeral **44**. It includes a generally horizontal handle **46** (shown vertical in the drawing for purposes of explanation) secured to a shaft **48** mounted for rotation on a ring member **50**. The ring member **50**, in turn, is mounted for rotation on shafts **52** and **54**. In this manner, up and down movement of the handle **46** will cause the shafts **52** and **54** to rotate; while movement of the handle forward or reverse will cause shaft **48** to rotate.

The shaft **48** is connected to the wiper brush of a rheostat **56** having its opposite ends connected to a source of alternating current voltage **58** having a grounded center point. A center tap on the rheostat **56** is grounded as shown. Thus, when the handle **46** is in its center position, zero output voltage will be applied from source **58** to lead **60**. However, it will be appreciated that the voltage from the alternating current source **58** applied to lead **60** will vary in magnitude as the handle **46** is moved further away from its center position, either forward or reverse. As the handle **46** moves forward from center, the output signal F_X increases. Similarly, when the handle **46** is moved backwardly from center, the output signal F_X increases, but its phase is reversed. The output signal F_X is utilized for control of the bucket movement along the X-axis. Movement of bucket **22** along the Y-axis is effected in a somewhat similar manner. That is, shaft **54** is connected to the wiper brush of a second rheostat **62** energized by source **64** and having a grounded center tap. In this manner, up and down movement of the handle **46** will cause the alternating current voltage on lead **66** to change in magnitude, the further the handle **46** is moved from its center position, the greater the magnitude of the alternating current signal. Furthermore, when the wiper brush of rheostat **62** is on one side of the grounded center tap, the signal applied to lead **66** will be 180° out of phase with respect to that when the wiper brush is on the other side of the center tap.

A signal proportional to the angle θ_1 is derived by means of a Selsyn transmitter **68** connected through lead **70** to a Selsyn receiver **72**. The stator and rotor of transmitter **68** are mechanically coupled to elements **32** and **34**, respectively, in such manner that relative rotation between elements **32** and **34** around pivot point P provides corresponding relative rotation between the stator and rotor of transmitter **68**. As is known, a Selsyn receiver-transmitter arrangement is such that rotation of the shaft of the transmitter **68** through a given arc will cause the shaft of the receiver **72** to also rotate through that arc. In a similar manner, a signal proportional to the angle θ_2 is derived by means of a Selsyn transmitter **74** which, in turn, is connected through lead **76** to Selsyn receivers **78** and **80**. The stator and rotor of transmitter **74** are mechanically coupled to elements **32** and **20**, respectively, in such manner that relative rotation between elements **20** and **32** around pivot point P provides corresponding relative rotation between the rotor and stator of transmitter **74**. Finally, the angle θ_3 is derived by means of a third Selsyn transmitter **82** connected through lead **84** to Selsyn receiver **86**. The stator and rotor of transmitter **82** are mechanically coupled to elements **10** and **32**, respectively, in such manner that relative rotation between elements **10** and **32** around pivot point **(0,0)** provides corresponding relative rotation between the stator and rotor of transmitter **82**.

The shafts of Selsyn receivers **78** and **86** are connected to two gears of a mechanical differential, generally indicated by the reference numeral **88**. The operation of the differential **88** is such that the number of degrees of rotation of bevel gear **90** is equal to the number of degrees of rotation of bevel gear **92** minus the number of degrees of rotation of bevel gear **94**. In this case, the gear **92** is rotated through a number of degrees proportional to the angle θ_2; while the gear **94** is rotated through a number of degrees proportional to θ_3. Hence, gear **90** will be rotated through a number of degrees proportional to $\theta_2-\theta_3$. By reference, again, to FIG. **2**, it can be seen that the angle α is equal to $(\theta_2-\theta_3)$. Consequently, the angular position of the gear **90** represents the angle α.

The gear **90**, in turn, rotates the rotor of a resolver, generally indicated by the reference numeral **96**. The resolver **96** may, for example, be of the type manufactured by the Ford Instrument Company, Long Island City, New York and includes a pair of windings **98** and **100** mounted at right angles to each other on a rotor element connected to the gear **90**. One or more stator windings are included in the resolver **96**, only one winding **102** being utilized in the present instance.

The basic operation of a resolver is exemplified by its computation of the sine and cosine of an angle. For this computation, the stator winding **102** is supplied with an alternating current voltage D of constant amplitude which is proportional to the fixed length of the dipper stick **20**. When the rotor of the resolver **96** rotates, the two rotor windings **98** and **100** provide output voltage whose amplitudes are proportional to the product of the signal applied to stator winding **102** times the sine and cosine, respectively, of the angle to which the rotor was turned. Thus, two output signals are derived, the one from winding **98** being identified in FIG. **1** as $D' \cos\alpha$, and that from winding **100** being identified as $D' \sin \alpha$.

In addition to being connected to the differential **88**, the Selsyn receiver **86** is connected to a second resolver **104** which again has two rotor windings **106** and **108** at right angles to each other. In this case, a signal S' whose amplitude is proportional to the length of stiff leg **32** is applied to the stator winding **110**. Thus, the output from rotor winding **106** is an electrical signal whose amplitude is proportional to $S' \cos\theta_3$ while that from rotor winding **108** is proportional to $S' \sin\theta_3$.

The signal from resolver **104** proportional to $S' \cos\theta_3$ is applied to summing point **112** along with the signal from resolver **96** proportional to $D' \cos\alpha$ and a fixed signal proportional to Y_B which is the fixed distance along the Y-axis between the origin (**0,0**) of FIG. **2** and the position (X_B, Y_B) of the sheave **16**. The signals proportional to $D' \cos\alpha$ and Y_B are applied to the summation point **112** in additive relation or plus (+) sense; while the signal proportional to $S' \cos\theta_3$ is applied to summing point **112** in subtractive relation or minus (−) sense. Hence, the output signal on lead **114** is proportional to:

$Y_B +' \cos\alpha - S' \cos\theta_3$.

By reference again, to FIG. **2**, it can be seen that:

16. $-Y_D = -S \cos\theta_3 + aD \cos\alpha$.

Consequently, the signal on lead **114** is proportional to:

$Y_B -_D$.

In a somewhat similar manner, the signal from resolver **104** proportional to $S' \sin\theta_3$ is applied to the summation point **116** along with the signal from resolver **96** proportional to $D' \sin\alpha$ and a fixed signal proportional to X_B which is the distance along the X-axis between the origin (**0,0**) of FIG. **2** and the position (X_B, Y_B) of sheave **16**. The signal proportional to X_B is applied to the summation point **116** in the plus (+) sense, while the other two are applied in the minus (−) sense. Hence, the output of summation point **116** on lead **118** is:

$X_B -' \sin\theta_3 - D' \sin\alpha$.

With reference, again, to the diagrams of FIG. **2**, we find that:

17. $-X_D = -S' \sin\theta_3 - D \sin\alpha$.

Consequently, the signal on lead **118** is proportional to:

$X_B -_D$.

The signals on leads **114** and **118** are applied to a polar resolver **120** which, in accordance with the equation:

18. $\beta = \tan^{11} X_B - X_D / Y_B - Y_D$

produces rotation in shaft **122** proportional to the angle β. This is applied to one bevel gear of a second mechanical differential **124** and to the rotor of resolver **130**. The opposite bevel gear is connected to gear **90** of differential **88** and, hence, its angular position is equal to the angle β. The angle assumed by the third bevel gear **126** of differential **124**, therefore, is equal to $\alpha+\beta$. The shaft of gear **126** is connected, as shown, to the rotors of two resolvers **128** and **132**.

Reverting again to the gear **90**, its shaft, whose angular position represents the angle α, is connected to the rotor of a resolver **134** having two stator windings **136** and **138**. The winding **136** is connected to lead **66** whereby a signal proportional to F_Y will be applied thereacross. Similarly, winding **138** is connected to lead **60** whereby a signal proportional to F_X will be applied thereacross. The output signal from rotor winding **140** of resolver **134**, therefore, will be proportional to:

$F_X \cos\alpha + F_Y \sin\alpha$.

This signal is applied via lead **142** to operational amplifier **144**. Operational amplifier **144**, in turn, actuates a servomotor **146** connected to the movable tap of a potentiometer rheostat **148** having its center point grounded as shown and its opposite ends connected to a source of alternating current supply voltage **150** having a grounded electrical center. The output from the movable tap on rheostat **148** is a signal proportional to the force H; and this signal is applied to the motor control circuit **30** for motor **28**. The signal proportional to H, however, is also applied to the stator winding **152** of the resolver **128**. In this manner, an output signal from rotor winding **154** of resolver **128** will be proportional to:

$H \sin(\alpha+\beta)$.

This is applied to the input of operational amplifier **144** in opposing relationship with the signal on lead **142** such that the output of the operational amplifier will be zero and the servomotor **146** will be stopped only when

$F_X \cos\alpha + F_Y \sin\alpha = H \sin(\alpha+\beta)$.

Any change in F_X or F_Y will unbalance the equation, and the servomotor **146** will be rotated until the equation is again brought back into balance.

The signals proportional to F_X and F_Y on leads **60** and **66** are applied to the two stator windings **156** and **158** of resolver **130**, whose rotor is connected to the output shaft **122** of resolver **120** such that its angular position is equal to the angle β. The output from rotor winding **160** of resolver **130**, therefore, is a signal proportional to $F_X \cos\beta - F_Y \sin\beta$ appearing on lead **162**. This signal is applied to the stator winding **164** of a resolver **166** whose rotor is connected to Selsyn receiver **80** connected, in turn, to Selsyn transmitter **74**. The shaft position of receiver **80** is equal to the angle θ_2. Hence, the output signal from rotor winding **168** of resolver **166** is:

$(F_X \cos\beta - F_Y \sin\beta) \sin\theta_2$.

This signal is applied via lead **170** to operational amplifier **172**, the output of the operational amplifier **172** being used to drive a servomotor **174**. The servomotor **174**, in turn, is connected to the movable tap on rheostat **176**, the center point of the rheostat being grounded and its opposite ends being connected to a source of alternating current voltage **178** having a grounded center point.

The output signal on the movable tap of rheostat **176** has an amplitude proportional to the magnitude of the desired force C and phase relation according to the direction of the desired force C as shown in FIG. **1** and is applied to the motor control circuit **42** for drive motor **40**. It is also applied via lead **180** to the stator winding **181** of resolver **132** having its rotor connected to gear **126** of differential **124** whereby the angular position of the rotor is equal to the sum of $\alpha+\beta$. The output of the resolver **132** on rotor winding **182**, therefore, is proportional to $C \sin(\alpha+\beta)$. This signal is applied to the stator winding **184** of a resolver **186** having its rotor connected to Selsyn receiver **72** connected to transmitter **68** whereby the shaft position of the receiver **72** will be equal to the angle θ_1. With the arrangement shown, the signal on rotor winding **188** of resolver **186** is $C \sin\theta_1 \sin(\alpha+\beta)$. This is applied to the input of operational amplifier **172** in opposing relationship with respect to the signal on lead **170** such that equation (15) above is satisfied to derive a null condition. That is, the servomotor **174** will be rotated to cause a change in the output signal proportional to the force C except when the quantity $C \sin\theta_1 \sin(\alpha+\beta)$ is equal to the quantity $(F_X \cos\beta - F_Y \sin\beta) \sin\theta_2$.

In the embodiment of FIG. **1**, up and down movement of the dipper stick **20** along its longitudinal axis is effected indirectly by means of the stiff leg **32** and crowd handle **34**. It is, of course, possible to actuate the dipper stick along its longitudinal axis directly as shown in FIG. **3** wherein a gear **190** engages a rack **192** on the dipper stick **20**. The gear **190**, in turn, is driven by means of motor **193** controlled via motor control circuit **194**. In this case, it is necessary to solve for the quantity D rather than C, and for this purpose equation (11) above can be used. That is:

$D = F_X \cos\beta - F_Y \sin\beta / \sin(\alpha+\beta)$

For this purpose, the output of resolver **130** to which signals proportional to F_X and F_Y are applied, is fed directly to an operational amplifier **196** which drives a servomotor **198** connected to a pot **200**. The signal proportional to force D is then fed in a feedback loop to a resolver **202**. That is, it is fed to the stator winding of that resolver, and the rotor of the resolver is rotated through an arc proportional to $\alpha+\beta$. This, of course, can be obtained from the differential **124**. The output from one of the rotor windings of resolver **202**, therefore, is proportional to D sin $(\alpha+\beta)$. This is applied to the input of operational amplifier **196** in opposing relationship with respect to the output of resolver **130**, whereby Equation (11) above is solved for D. Derivation of the quantity H, under these circumstances, will be the same as that shown in connection with FIG. 1.

In both embodiments disclosed in FIGS. 1 and 3, the following common denominators are found. The dipper stick **20** is in movable engagement with the boom **14** in transverse relation thereof for movement within the vertical plane in which the longitudinal axis of the boom lies. The dipper stick **20** is pivotable around a pivot supported by a member carried by the main frame. In FIG. 1, the pivot P is supported by the member **32** (the stiff leg) which is carried by the main frame **10**. In FIG. 3, the pivot around which the dipper stick is swingable is supported by the member **14** (the boom) which is carried by the main frame **10**. Thus in both cases, the dipper stick is pivotable relative about a horizontal axis at right angles to the transverse movement of the dipper stick and to the aforementioned vertical plane.

Reverting again to Equation (1) given above, both sides of the equation can be multiplied by $\sin\theta_2$ to derive the following equation:

19. $F_X \sin \theta_2 = D \sin \alpha \sin \theta_2 + H \sin \beta \sin \theta_2$

From Equation (3) given above, however, we see that $C \sin \theta_1$ equals $D \sin \theta_2$. Consequently, Equation (19) can be rewritten as follows:

20. $F_X \sin \theta_2 = C \sin \alpha \sin \theta_1 + H \sin \beta \sin \theta_2$

Similarly, Equation (2) given above can be modified as was Equation (1) to derive:

21. $F_Y \sin \theta_2 = -C \cos \alpha \sin \theta_1 + H \cos \beta \sin \theta_2$

By utilizing signals proportional to drive motor currents for the quantities C and H in the foregoing equations, and since the angles θ_1, θ_2, α and β are already derived from the system of FIG. 1, electrical signals proportional to actual F_X and actual F_Y (actual force components on bucket) can be derived and applied to torque motors which resist the movement of the handle **46** of the two-axis switch **44**.

Circuitry for accomplishing this is shown in FIG. 4 wherein the signal C_1 is a direct current signal proportional to the armature current of drive motor **40** and the signal H_1 is a direct current signal proportional to the armature current of drive motor **28**. The signal C_1 is converted to an alternating current signal in inverter **204**; and similarly, the signal H_1 is converted into an alternating current signal in inverter **206**. The output of inverter **206**, comprising an alternating current signal having an amplitude proportional to H_1, is then applied to the stator winding of a resolver **208**, the rotor of this resolver being connected, for example, to the Selsyn receiver **78** whereby it will assume the angle θ_2. The output of the resolver on one of its rotor windings is, therefore, $H_1 \sin\theta_2$. This is applied via lead **210** to a second resolver **212** and, more specifically, to the stator winding of resolver **212**. The rotor of resolver **212** is connected, for example, to the output of polar resolver **120** shown in FIG. 1; and output signals are derived from both of its rotor windings, one of said signals on lead **214** being proportional to $H_1 \sin \theta_2 \sin \beta$ and the other output signal on lead **216** being proportional to $H_1 \sin \theta_2 \cos \beta$.

In a similar manner, the output of inverter **204** is applied to the stator winding of a resolver **218**, the rotor of the resolver being connected, for example, to Selsyn receiver **72** of FIG. 1 such that the rotor will assume the angle θ_1. The signal derived from one of the rotor windings of the resolver **218** on lead **220** will, therefore, be proportional to $C \sin \theta_1$. This is applied to the stator winding of resolver **222** having its rotor connected, for example, to gear **90** of FIG. 1 such that it assumes the angle α. This will produce on one rotor winding a signal proportional to $C_1 \sin \theta_1 \sin \alpha$ on lead **224** and will produce on its other rotor winding a signal on lead **226** proportional to $C_1 \sin \theta_1 \cos \alpha$.

The signals on leads **224** ad **214** are applied as inputs to an operational amplifier **228** which drives a servomotor **230** to cause rotation of a movable wiper on a rheostat **232**. The output of the rheostat **232**, comprising a signal proportional to actual F_X, is applied to the stator winding of resolver **234** having its rotor connected, for example, to Selsyn receiver **78** such that it will assume the angle θ_2. The output of resolver **234**, therefore, is $F_X \sin \theta_2$. It can be seen, therefore, that since the signals on leads **224** and **214** are applied to the operational amplifier **228** with positive polarity while the signal from resolver **234** is applied with negative polarity, the output of the amplifier **228** will be zero only when:

$F_x \sin \theta_1 \sin \alpha + H_1 \sin \theta_2 \sin \beta$.

In a similar manner, the signals on leads **226** and **216** are applied to another operational amplifier **236** which drives servomotor **238**. The servomotor **238**, in turn, drives rheostat **240**, and the output of the rheostat is a signal proportional to actual F_Y. This signal is applied to the stator winding of resolver **242** having its rotor connected, for example, to Selsyn receiver **78** to assume the angle θ_2 whereby the output of the resolver is $F_Y \sin \theta_2$.

It can be seen that the output of the operational amplifier **236** will be zero only when:

$F_Y \sin \theta_2 = -C \sin \theta_1 \cos \alpha + H_1 \cos \beta \sin \theta_2$. The signal proportional to actual F_X is applied to a torque motor **244** on shaft **48** which resists movement of the handle along the X-direction; while the signal proportional to actual F_y is applied to a second torque motor **246** connected to shaft **54**. Hence, as the forces in the X and Y-directions increase, so also does the retarding force imposed by the torque motor **244** or **246**, thereby giving the operator a "feel" of the actual forces imparted on the digging bucket of the shovel.

Although the invention has been shown in connection with certain specific embodiments, it will be readily apparent to those skilled in the art that various changes in form and arrangement of parts may be made to suit requirements without departing from the spirit and scope of the invention.

We claim as our invention:

1. In a control system for an excavating shovel of the type having a main frame, a boom extending from the main frame, a dipper stick pivotally mounted relative to the main frame, first motor means for reciprocating the dipper stick in a direction transversely of the main boom, and second motor means for causing said dipper stick to swing through an arc about its pivotal connection by means of a hoist cable which is connected to the lower end of said dipper stick and passes around a sheave at the outer end of said boom; the improvement comprising a single two-axis master controller movable along a first course and along a second course at right angles to the first course for controlling horizontal and vertical force components on a digging bucket at the lower end of said dipper stick, means for producing a first electrical signal proportional to the desired horizontal force component on said bucket and which varies as a function of the position of said controller along said first course, means for producing a second electrical signal proportional to the desired horizontal force component on said bucket and which varies as a function of the position of said controller along said first course, means for producing a second electrical signal proportional to the desired vertical force component on said bucket and which varies as a function of the position of said controller along said second course, and circuit means responsive to said first and second electrical signals for controlling the horizontal and vertical force components on said bucket and the position of said bucket.

2. The improvement of claim 1 wherein the forces on the bucket in horizontal and vertical directions are determined by the amount of movement of the master controller along said first and second courses, respectively.

3. The improvement of claim 1 wherein the master controller is of the type comprising a control handle which can be rotated about a first axis on either side of a central position and rotated about a second axis on either side of the central position, said first axis intersecting the second axis.

4. The improvement of claim 1 wherein said circuit means includes means for producing a third electrical signal proportional in magnitude to the angle between said hoist cable and vertical, and means for producing a fourth electrical signal proportional in magnitude to the acute angle between said dipper stick and vertical.

5. The improvement of claim 4 wherein said shovel is of the knee-action type having a stiff leg pivotally connected at its opposite ends to the upper and lower ends of said dipper stick and boom respectively, and a crows handle pivotally connected to the upper end of said stiff leg and dipper stick, said circuit means including means for producing a fifth electrical signal proportional in magnitude to the angle between said crowd handle and stiff leg, and means for producing sixth electrical signal proportional in magnitude to the angle between said stiff leg and said dipper stick.

6. The improvement of claim 5 wherein the first motor means is operatively connected to said crowd handle and controlled by a seventh electrical signal proportional to:

$$\frac{(F_X \cos\beta - F_Y \sin\beta)\sin\theta_2}{\sin\theta_1 \sin(\alpha+\beta)}$$

where F_X and F_Y are quantities proportional to movement of said controller along its first and second course, respectively, α is the angle between said dipper stick and vertical, β is the angle between said hoist cable at its connection to the dipper stick and vertical, θ_1 is the angle between said stiff leg and crowd handle, and θ_2 is the angle between said stiff leg and dipper stick.

7. The improvement of claim 6 including means for producing eighth and ninth electrical signals proportional to $(F_X \cos \beta-F_Y \sin\beta)\sin\theta_2$ and $C\sin(\alpha+\beta)$, respectively, where C is proportional to the magnitude of said seventh electrical signal controlling said first motor means, and a servosystem responsive to said eighth and ninth signals for actuating said first motor means except when:

$(F_X \cos\beta-F_Y \sin\beta)\sin\theta_2-C\sin\theta_1\sin(\alpha+\beta)=0$.

8. The improvement of claim 4 wherein the second motor means is operatively connected to said hoist cable and controlled by a fifth electrical signal proportional to:

$$\frac{F_X \cos\alpha + F_Y \sin\alpha}{\sin(\alpha+\beta)}$$

where F_X and F_Y are quantities proportional to movement of said controller along its first and second courses, respectively, α is the angle between said dipper stick and vertical, and β is the angle between said hoist cable at its connection to the dipper stick and vertical.

9. The improvement of claim 8 including means for producing sixth and seventh electrical signals proportional to $F_X \cos\alpha+F_Y \sin\alpha$ and $H\sin(\alpha+\beta)$, respectively, where H is proportional to the magnitude of said fifth electrical signal controlling said second motor means, and a servosystem responsive to said sixth and seventh signals for actuating said second motor means except when:

$(F_X \cos\alpha+F_Y \sin\alpha)-H\sin(\alpha+\beta)=0$.

10. The improvement of claim 1 including means responsive to the currents through said first and second motor means for producing third and fourth signals, the third signal being proportional to the force on said digging bucket in the horizontal to direction and the fourth signal being proportional to the force on said digging bucket in the vertical direction, means responsive to the third signal for producing restraining forces on said controller as it is moved along one of said courses, and means responsive to the fourth signal for producing restraining forces on said controller as it is moved along the other of said courses.

11. The combination of claim 4 wherein said circuit means includes means for producing a fifth signal, and means responsive to said fifth signal for controlling said first motor means, said fifth signal being proportional to

$$\frac{F_X \cos\beta - F_Y \sin\beta}{\sin(\alpha+\beta)}$$

where F_X and F_Y are quantities proportional to movement of said controller along its first and second courses respectively, θ is the angle between said dipper stick and vertical, and β is the angle between said hoist cable and vertical at the dipper stick.

12. The combination of claim 11, wherein said circuit means includes means for producing a sixth signal, and means responsive to the sixth signal for controlling said second motor means, said sixth signal being proportional to

$$\frac{F_X \cos\alpha + F_Y \sin\alpha}{\sin(\alpha+\beta)}$$

13. The combination as in claim 5 wherein said circuit means comprises means for producing a seventh signal proportional to

$$\frac{(F_X \cos\beta - \sin\beta)\sin\theta_2}{\sin\theta_1 \sin(\alpha+\beta)}$$

means responsive to the seventh signal for controlling said first motor means, means for producing an eighth signal proportional to

$$\frac{F_X \cos\alpha + F_Y \sin\alpha}{\sin(\alpha+\beta)}$$

and means responsive to the eighth signal for controlling said second motor means, F_X and F_Y being quantities proportional to movement of said controller along its first and second courses, respectively, α being the angle between said dipper stick and vertical, β being the angle between said hoist cable and vertical at its connection to the dipper stick, θ_1 being the angle between said stiff leg and crowd handle, and θ_2 being the angle between said stiff leg and dipper stick.

14. The method of controlling an excavating shovel of the type having a main frame, a boom extending from the main frame, a dipper stick pivotally mounted relative to the main frame and having a bucket at its lower end, first motor means for reciprocating the dipper stick transversely of the main boom, and second motor means for causing said dipper stick to swing through an arc about its pivotal connection by means of a hoist cable which is connected to the lower end of said dipper stick and passes around a sheave at the outer end of said boom, said method comprising the steps of controlling said first motor means in accordance with the relation

$$\frac{(F_X \cos\beta - F_Y \sin\beta)}{\sin(\alpha+\beta)}$$

and controlling said second motor means in accordance with the relation

$$\frac{(F_X \cos\alpha + F_Y \sin\alpha)}{\sin(\alpha+\beta)}$$

F_X and F_Y being quantities proportional to desired horizontal and vertical movements respectively, of said bucket, α being the angle between said dipper stick and vertical, and β being the angle between said hoist cable and vertical at its connection to the dipper stick.

15. The control system of claim 1 wherein said circuit means responsive to said first and second electrical signals translates said first and second signals proportional to the desired horizontal and vertical force components into third and fourth signals which vary as a function of the instantaneous desired force components in line with said dipper stick and in line with said hoist cable respectively, means for applying said third signal to said first motor means to control the same, and means for applying said fourth signal to said second motor means to control the same.