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.
FIG. 1.
FIG. 2.

\[
F_x \cos \beta - F_y \sin \beta
\]

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 continuously 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 determined 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 countering 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 restrained 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, the bucket 16.

The boom 14 is formed from two identical laterally spaced elongate members, one only 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.

Pivotaly 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 39 controlled by motor control circuitry 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 ground position.

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 (Xp1, Yp1); while the position of the digging bucket is identified as point (Xp2, Yp2). 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 \( \theta_c \); the angle between dipper stick 20 and stiff leg 32 is identified as \( \theta_d \); the angle between the stiff leg 32 and vertical is identified as \( \theta_2 \). The angle between the hoist cable 24 and vertical is identified as \( \beta \), while the angle between vertical and the dipper stick 20 is identified as \( \alpha \). The forces imparted by the hoist cable 22 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 forces imparted by 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. \( F_y = D \sin \beta \sin \beta \)
2. \( F_y = D \cos \alpha H \cos \beta \)
3. \( C \sin \beta = A H \sin \beta \)

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

4. \( F_y \cos \alpha = D \sin \alpha \cos \alpha + H \sin \beta \cos \alpha \)
5. \( F_y \sin \alpha = D \sin \alpha \sin \alpha + H \sin \beta \sin \alpha \)

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

6. \( F_y \cos \alpha + F_y \sin \alpha = D \sin \alpha \cos \alpha + H \sin \beta \cos \alpha \)
7. \( F_y \cos \alpha + F_y \sin \alpha = D \sin \alpha \sin \alpha + H \sin \beta \sin \alpha \)

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

8. \( F_y \cos \beta = D \cos \alpha \sin \alpha + H \sin \beta \cos \beta \)
9. \( F_y \sin \beta = D \cos \alpha \cos \alpha + H \sin \beta \sin \beta \)

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

10. \( F_y \cos \alpha - F_y \sin \alpha = D \sin \alpha \cos \alpha - H \sin \beta \cos \sin \alpha \)
11. \( F_y \cos \alpha - F_y \sin \alpha = D \cos \alpha \sin \alpha - H \sin \beta \sin \alpha \)

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

12. \( D = C \sin \alpha \sin \beta \)

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

13. \( (F_y \cos \alpha - F_y \sin \alpha) \sin \beta = C \sin \alpha \sin \beta \sin \alpha \cos \beta \)

In an electrical servocontrol system wherein electrical signals from a single master controller proportional to desired \( F_y \) and desired \( F_x \) must be balanced against electrical proportional forces to produce a zero or null output, Equations (7) and (13) above may be rewritten as follows:

14. \( F_y \cos \alpha + F_y \sin \alpha = H \sin \alpha \cos \beta \)
15. \( F_x \cos \beta - F_y \sin \beta = C \sin \beta \sin \alpha \cos \beta \)

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 \( \alpha, \beta, \theta_c \), and \( \theta_d \) can be derived.

Circuitry for accomplishing the foregoing is shown in FIG. 1 and includes a 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 \( V \). Reversing \( V \) will cause a grounded center tap on the rheostat 56 to be grounded as shown. Thus, when the handle 46 is in its center position, zero output voltage will be applied from source on lead 58 to lead 60. However, it will be appreciated that the voltage from the alternating current source \( V \) 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 backward from center, the output signal \( F_x \) decreases, 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 54 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 \( \theta \), 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 relative 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 \( \theta \), 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 30, respectively, in such manner that relative rotation between elements 20 and 32 around pivot point \( P \) provides corresponding relative rotation between the stator and rotor of transmitter 74. Finally, the angle \( \theta \), 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 \( \theta_2 \), while the gear 94 is rotated through a number of degrees proportional to \( \theta_1 \). Hence, the gear 90 will be rotated through a number of degrees proportional to \( \theta_2 - \theta_1 \). By reference, again, to FIG. 2, it can be seen that the angle \( \alpha \) is equal to \( (\theta_2 - \theta_1) \). Consequently, the angular position of the gear 90 represents the angle \( \alpha \).

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, for the sine 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 rotates, 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 a system 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, 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 $S' \cos \beta$, while that from rotor winding 108 is proportional to $S' \sin \beta$.

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

$$Y_a + S' \cos \beta \cdot D' \cos \alpha$$

Consequently, the signal on lead 114 is proportional to:

$$Y_a = Y_a + S' \cos \beta \cdot D' \cos \alpha$$

In a somewhat similar manner, the signal from resolver 104 proportional to $S' \sin \beta$ 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 $X_a$ which is the distance along the X-axis between the origin (0,0) of FIG. 2 and the position $(X_a, Y_a)$ of the shelve 16. The signal proportional to $X_a$ 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:

$$X_a \sin \beta - D' \sin \alpha$$

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

$$X_a = X_a \sin \beta - D' \sin \alpha$$

Consequently, the signal on lead 118 is proportional to:

$$X_a = X_a \sin \beta - D' \sin \alpha$$

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

$$\beta = \tan^{-1} \frac{X_a - X_b}{Y_a - Y_b}$$

produces rotation in shaft 122 proportional to the angle $\beta$. 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 $\beta$. 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 $\alpha$, is connected to the rotor of a resolver 134 having two stator windings 136 and 138. The winding 136 is connected to lead 126 whereby a signal proportional to $F_x$ will be applied thereacross. Similarly, winding 138 is connected to lead 60 whereby a signal proportional to $F_y$ 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 volt.
The signals on leads 234 and 214 are applied as inputs to an operational amplifier 228 which drives a servomotor 230 to rotate a movable wiper on a rheostat 232. The output of the rheostat 232, comprising a signal proportional to actual \( F_S \), 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 \( \theta_S \). The output of resolver 234, therefore, is \( F_S \sin \theta_S \). It can be seen, therefore, that since the signals on leads 234 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:

\[
F_S \sin \theta_S \sin \alpha + H_S \sin \beta = 0
\]

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 \( F_T \). 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 \( \theta_T \) whereby the output of the resolver is \( F_T \sin \theta_T \). It can be seen that the output of the operational amplifier 236 will be zero only when:

\[
F_T \sin \theta_T = -C \sin \alpha + H \cos \beta \sin \theta_T
\]

The signals on leads 224 and 214 are applied as inputs to an operational amplifier 226 which drives a servomotor 238 connected to the resolver 234 which resists movement of the handle along the X-direction; while the signal proportional to actual \( F_S \) 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, 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 shoveling boom on either side of the shovel shoveling boom, comprises a control system 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 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 one 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 knuckle-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 crowd 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:

\[
\frac{F_x \cos \beta - F_y \sin \beta}{\sin \theta_1 \sin (\alpha + \beta)}
\]

where \(F_x\) and \(F_y\) are quantities proportional to movement of said controller along its first and second course, respectively, \(\alpha\) is the angle between said dipper stick and vertical, \(\beta\) is the angle between said hoist cable at its connection to the dipper stick and vertical, \(\theta_1\) is the angle between said stiff leg and crowd handle, and \(\theta_2\) 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 \(F_x \cos \beta + F_y \sin \beta\) and \(C \sin \theta_1 \sin (\alpha + \beta)\), 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:

\[
F_x \cos \alpha + F_y \sin \alpha \sin (\alpha + \beta)
\]

where \(F_x\) and \(F_y\) are quantities proportional to movement of said controller along its first and second courses, respectively, \(\alpha\) is the angle between said dipper stick and vertical, and \(\beta\) 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 main 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 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, \(\theta\) is the angle between said dipper stick and vertical, and \(\beta\) 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:

\[
\frac{F_x \cos \beta - \sin \beta}{\sin \theta_1 \sin (\alpha + \beta)}
\]

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, \(\alpha\) being the angle between said dipper stick and vertical, \(\beta\) being the angle between said hoist cable and vertical at its connection to the dipper stick, \(\theta_1\) being the angle between said stiff leg and crowd handle, and \(\theta_2\) 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:

\[
\frac{F_x \cos \alpha + F_y \sin \alpha}{\sin (\alpha + \beta)}
\]

where \(F_x\) and \(F_y\) being quantities proportional to desired horizontal and vertical movements respectively, of said bucket, \(\alpha\) being the angle between said dipper stick and vertical, and \(\beta\) 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.