ABSTRACT

A blade stabilizer system that substantially isolates the movement of the machine frame from the blade wherein various positions of the blade with respect to the frame are established by two laterally spaced adjustable hydraulic cylinders connected to the blade uses at least two transversely spaced accelerometers secured to the frame to respond to vertical movement of the frame and employs the outputs of the accelerometers to extend or retract the hydraulic cylinders in proportion to the acceleration sensed so that the blade is isolated from movement of the frame and continuously oriented with respect to a horizontal plane. A third accelerometer for affording an indication of the blade angle with respect to vertical is provided, as is circuit means for incorporating the latter accelerometer with the previously mentioned accelerometers.

7 Claims, 7 Drawing Figures
BLADE STABILIZER FOR EARTH WORKING APPARATUS

BACKGROUND OF THE INVENTION

Automatic controls for cutting implements on earth working machinery are achieving grades within specification of ±0.5% inch in 10 feet of graded surface. In particular, motorgraders have been equipped with such systems to increase the speed of grading operations to such specification. As a collateral benefit, the automatically controlled machines can be operated by semi-skilled operators, whereas the manually controlled machines require a great deal of skill and dexterity on the part of the operator to achieve the above specifications.


In general, the system illustrated in the above referenced patents depends on some type of pendulum of a gravity-responsive type, usually damped in some manner, to provide a vertical reference relative to which the slope of the blade is constantly adjusted. While such systems are feasible, the severe conditions experienced in earth working environments cause a number of complex errors to be introduced into the control system. Complex motion of the frame, distortion thereof, inertia of components and response lag time lead to oscillatory conditions in the closed loop control system that becomes even more acute as the forward speed of the machine is increased. In fact, the correction signal can become 180° out of phase with the sensed error leading to scalloping. Thus, in the closed loop control systems, some undesirable instability has been experienced.

The present invention exploits the advantages afforded by the above listed prior art and affords further enhancement of the accuracy and speed with which a desired earth surface configuration can be achieved. Because the portion of the earth surface traversed by the wheels or tracks that support the machine frame is irregular, it is essential that the blade be moved rapidly with respect to the frame in order to achieve a smooth finished surface. While at very slow speeds a machine operator can make adjustments of the blade with respect to the frame with sufficient dexterity to secure the desired smooth finished surface, at a higher speed automatic control is essential, as even a skilled operator does not have the agility to react in time. Short response time of the automatic control system is essential at high speeds, and the present invention affords higher speed response to error signals.

It is thus an object of the present invention to provide a blade stabilizing system that responds quickly and accurately to frame movement substantially isolated from the earth working blade. The present invention achieves this object by providing a pair of accelerometers secured to the frame at transversely spaced apart sites and providing means that automatically move the blade vertically of the frame in accordance with the output of the accelerometers.

Another object is to provide a system for moving the blade at a variable rate proportional to the rate of frame movement. This object is achieved in the present invention by integrating the accelerometer output so as to output a signal proportional to the velocity of the frame movement away from a null position and to apply the velocity related signal to the blade moving links.

A further object of the present invention is to provide an integrated system which automatically maintains the desired slope and grade settings as well as compensating for vertical frame movements. This object is achieved by providing a third accelerometer which has an output proportional to the displacement of the blade cutting edge from the vertical reference plane and feeding the output of such accelerometer into the blade positioning system.

Other objects, features and advantages of the present invention will be more apparent after referring to the following specification and accompanying drawings.

SUMMARY OF THE INVENTION

A blade stabilizer according to this invention is associated with an earth working vehicle having an earth working implement controllably suspended therefrom from spaced apart locations and includes a first accelerometer attached adjacent to one of the spaced apart locations and a second accelerometer attached adjacent to the other spaced apart location, each accelerometer having means for generating a signal proportional to its movement as to magnitude and direction and circuits connected to the accelerometers and controls moving the earth working implement whereby displacement of the vehicle from a position will cause the implement to be immediately adjusted to maintain its prior position.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a simplified block diagram of the present invention incorporated into a motor grader.

FIG. 2 is a fragmentary view of the motor grader of FIG. 1 showing the system for providing a signal proportional to the position of the blade relative to the vertical reference.

FIG. 2A is a fragmentary view of a portion of FIG. 2.

FIG. 3 is a detailed block diagram of a control system according to the present invention.

FIG. 4 is a detailed circuit diagram of the electronic portion of the system of FIG. 3 which provides control functions based on a signal proportional to blade position relative to the vertical reference and other signals related to magnitude and direction of frame motion.

FIG. 5 is a schematic diagram of an accelerometer employed in the present invention.

FIG. 6 is a block diagram of a stabilizer system according to the present invention.

FIG. 7 is a block diagram showing a system according to the invention similar to FIG. 3 but affording means for selecting one of several modes of operation of the system.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring more particularly to the drawings and specifically to FIG. 1, reference numeral 10 indicates a broken away front portion of a motor grade which includes a longitudinally extending frame member 12...
with an integral vertically extending bolster 14. At the lower end of the bolster, the front wheels 16 of the motor grader are supported. Secured to bolster 14 is a drawbar 18 with circle 20 rotatably attached to the rear portion of the drawbar. Transversely spaced blade brackets 22 mount earth working blade 24 on the drawbar circle in a conventional manner. A gear housing 26 has a pinion (not shown) which engages teeth on circle 20 to rotate the circle and thus position the blade at any desired angle relative to the longitudinal axis of the motor grader. The drawbar is further stabilized by a conventional side shift mechanism (not shown).

Vertically located above the blade 24 on frame member 12 is a right hand bracket 28 and a left hand bracket 30 extend from the frame member so their distal ends are spaced from one another. These brackets are rigidly mounted to the frame member and at the distal end of bracket 28 is a hydraulic cylinder 32 and at the distal end of bracket 30 is a hydraulic cylinder 34, both of which are gimbaled. The rods of the respective hydraulic cylinders are connected to spaced apart points on the drawbar 18 through circle 20 and brackets 22 to the blade so that the position of the cylinder rods determines the orientation of the blade relative a horizontal plane.

Secured to bracket 28 adjacent to its associated cylinder 32 is an accelerometer 36 and secured to bracket 30 adjacent to its associated cylinder 34 is an accelerometer 38. These two accelerometers produce signals that have a magnitude proportional to the rate and direction of movement of the bracket on which it is secured.

The details of construction of accelerometers 36 and 38 do not, per se, constitute a part of the present invention; however, general details of construction of the accelerometers are shown schematically in FIG. 5. FIG. 5 schematically depicts one suitable commercially available accelerometer which has been used in the present invention, such accelerometer being commercially available from the Systron Donner Corporation as model 4310. A suitable accelerometer can include a mass M which is supported on a horizontally extending shaft SH by a radial arm RA. Also supported on shaft SH is a coil structure C which is disposed within the field of a generally U-shaped permanent magnet U. Coil C is energized via an amplifier A, the output of which is returned to ground through a resistor R so the output of amplifier A is established by a position detector PD which detects the relative position of mass M. In the quiescent state, amplifier A produces a current through coil C and load resistor R to maintain mass M in the position shown in FIG. 5. When the frame bracket on which the accelerometer is mounted experiences acceleration in a direction V, mass M moves toward or away from position detector PD whereby the output of amplifier A is altered. The amplifier produces a signal in coil C of a magnitude and polarity to restore the mass to the null position and the polarity and magnitude of such signal is reflected across resistor R so a voltage $E_0$ across resistor R is proportional to the output of amplifier A, which in turn is proportional to the magnitude and direction of acceleration of the accelerometer from its null position.

With respect to FIG. 1 the output of accelerometer 36 appears on a conductor 40 and the output of accelerometer 38 appears on a conductor 42. Conductors 40 and 42 are connected respectively to integrating filters 44 and 46 and because the output signal on conductors 40 and 42 is proportional to the time rate of change of velocity of frame brackets 28 and 30, the output of integrators 44 and 46 is proportional to the velocity. With the outputs of the integrating circuits connected through amplifiers 48 and 40 respectively to electrohydraulic valves 52 and 54, the output of electrohydraulic valve 52 is used to control cylinder 32 and the output of electrohydraulic valve 54 controls cylinder 34, moving blade 24 in a direction opposite from movement of the respective frame brackets 28 and 30. Because the amount of movement is proportional to the velocity of the movement of the frame brackets, the blade is rapidly positioned and is effectively isolated from vertical movements of the frame and maintained in a constant orientation with respect to a horizontal plane.

In addition to being isolated from the movements of the vehicle frame, blade 24 must be positioned to produce the desired grade. In this context, grade refers to the depth of cut or the distance from a hypothetical horizontal reference plane while slope refers to the angle of the cutting edge of blade 24 with respect to such horizontal plane. For maintaining the correct grade, a wand mechanism is employed, such mechanism being disclosed in more detail in U.S. Pat. No. 3,495,663. For the present disclosure, it is sufficient to note that an external grade wire 58 is contacted by a wand 60 which is linked to the shaft of a potentiometer 62. Because one portion of potentiometer 62 is fixed with reference to the blade, the output of potentiometer 62 is proportional to the position of its end of the blade with respect to wire 58. Thus an output from the potentiometer can be transmitted by a conductor 64 to a summing junction 66, that also has an input from a hand set potentiometer 68 allowing the operator to adjust the blade to the desired grade. Thus, so long as one end of the blade resides in the proper relationship with the grade wire, this summing amplifier has a zero output; however, when the blade position diverges from the desired grade, summing junction 66 produces a proportional output which is amplified by amplifier 70 and fed to summing junction 72 with the other input from integrating circuit 44. Thus cylinder 32 moves to compensate for the combined effect of unwanted vertical movement of frame bracket 28 and the divergence of the blade from the desired grade.

For the control system to generate a signal proportional to the correct blade slope, a resolver 74 is installed within bolster 14 for cooperation with the forward end of a drawbar 18. Structural details of the resolver are disclosed in more detail in U.S. Pat. No. 3,328,905, and the resolver adjusts the output of its circuit so it is proportional to the slope of blade 24 notwithstanding the rotational position of blade 24 and circle 20. More specifically and in reference to FIGS. 2 and 2A, a cam 76 is illustrated which is driven by ring drive mechanism 26 so that the position of the cam corresponds to the angular position of circle 20 and blade 24 with reference to the drawbar 18. The position of cam 76 is transmitted by a cam follower 78 and a flexible cable 80 through a sheave 82 and turns and controls a table 84. Supported diamentically of table 84 is a pivotally mounted T-bar 86, the horizontal portion of which is always parallel to the cutting edge of blade 24. Thus as the angular position of the blade varies the rotational position of a yoke 88, the yoke is adjusted to an accurate reflection of slope notwithstanding the degree
of rotation of circle 20 and the blade 24. To produce an output related to the position of the yoke, an accelerometer 90 is secured to shaft portion 88S of yoke 88 so as to produce an output signal proportional to any change in blade slope. More specifically, as shown in FIG. 5, accelerometer 90 is secured to shaft 88 whereby mass M is oriented so that its radial arm RA is vertical when the blade is transverse to the line of flight of the motor grader. Thus, it will be appreciated as the blade is rotated on circle 20, the ball resolver will turn the shaft portion 88S supporting the accelerometer so that the radial arm RA is disposed in an angular relationship with reference to the vertical. This angular displacement of the radial arm will directly compensate for the change introduced by the rotation of the blade on the circle so the output will remain directly proportional to changes in slope. This is true since the mass M is responsive to gravity even though the accelerometer generates a signal to offset the movement of the mass due to gravity when it is angularly disposed. However, since this is a steady state condition and the accelerometer is connected to the control circuits through an AC couple, no signal will pass until a change occurs. Thus, with this arrangement, any rotational movement of the drawbar about its longitudinal axis will develop a signal in accelerometer 90 which is proportional to the rotational component of the drawbar and the angular disposition of arm RA with reference to the vertical as set by the resolver.

Referring to FIG. 1, the output of accelerometer 90 is connected to a summing junction 92 which has an input from a manually set potentiometer 94, the position of which is established by the operator in accordance with the desired slope. In other words, summing junction 92 has an output only when the slope of blade 24 diverges from the desired or preselected slope. The output of summing junction 92 is amplified by an amplifier 95 and conducted to a summing junction 96, the other input of which is from integrating circuit 46. Thus, cylinder 34 is activated to compensate for movement of both frame bracket 30 and an accelerometer 90 to maintain the slope of blade 24 to the correct degree.

The system of FIG. 1 is shown in somewhat more detail in FIGS. 3 and 4 and corresponding elements bear the same reference numerals. In FIG. 3 a switch 98 is accessible to the operator of the equipment, is used to select one of three operating modes. In the uppermost position, the slope of the blade 24 is generally controlled by the right hand cylinder 32 and the grade of the blade is generally controlled by the left hand cylinder 34. In the lowermost position, the controls are reversed, i.e., the slope is generally controlled by the right cylinder 32. In the central switch position the circuitry is rendered ineffective and blade control is achieved manually by valves associated with hydraulic lines 100A-100D. Switch 98 has two decks, indicated as 98A and 98B, so when switch 98 is in the central or manual position, it turns off hydraulic valves 102 and 104 which in turn move check valves 106A-106F to a closed position so that the sole hydraulic control occurs at connections 100A-100D. When switch 98 is in either of the extreme positions, valves 102 and 104 are moved to the open position whereby hydraulic fluid under pressure flows from source 107 to check valves 106A-106F thereby allowing activating electrohydraulic valves 52 and 54 to respond to control signals.

The system of FIG. 3 also includes a sensitivity control 110 which is manually set by the operator. It is a four-position switch, the upper position of which connects accelerometer signals 38 and 36 directly through to junction points 96 and 72 respectively. In the center two positions, switch 110 switches in different values of resistance in series with the accelerometer output so that the signals from accelerometers 38 and 36 are attenuated. In rough grading operations, the uppermost position of switch 110 is employed whereas in fine grading operations, one or the other of the center positions is employed. In the lowermost position, the effect of accelerometers 38 and 36 is removed from the circuit.

For affording the operator a indication of the slope and/or grade changes, a meter 112 is provided, a two-position switch 114 being associated with the meter. When the system of the invention is not correcting the meter gives zero indication. When, however, the grade or slope system is correcting the meter gives an indication of the amount of correction being applied by the system.

The stabilizing system of the present invention can also be employed in grading equipment wherein slope and grade control are effected manually or from external references. Referring to FIG. 6, there is shown in schematic form a portion of the system of FIG. 1 and similar characters of reference are employed to indicate similar parts. In the absence of automatic slope and grade controls, however, it is desirable to employ a position transducer on each side of the blade to indicate the position between the respective sides of the blade and the respective frame bracket 28 or 30. More particularly, there is a position transducer 116 that produces an electrical signal proportional to the vertical position of the right side of the blade 24 relative frame bracket 28. A position transducer 118 produces an electric signal proportional to the vertical position of the left side of blade 24 relative frame bracket 30. Such signals are transmitted to summing junctions 120 and 122 respectively. These summing junctions additionally have manual operator inputs, 124 and 126 respectively, by which the operator manually introduce a signal indicative of the desired grade and slope settings. Accordingly the system of FIG. 6 affords stabilization against vertical movement of the frame in a system where slope and grade are set manually.

FIG. 7 indicates a circuit combining the relative simplified mode of operation of FIG. 6 into the system of FIGS. 1-4 in order to provide a grade control and stabilizing system with substantial versatility. A mode switch 98' has four positions, as contrasted with switch 98 in FIG. 3 which has only three positions. The fourth position readies the circuit of FIG. 7 for operation in the mode shown in FIG. 6. For improved stability additional integrating filters 44' and 46' are added to the output of the stabilizing accelerometers 36 and 38 and system operation proceeds as described hereinabove in connection with FIG. 6. Whether the slope and grade signals are introduced manually from controls 124 and 126 or automatically, the use of the stabilizer system responds to frame movements caused by the rear wheels on the earth working machine. Accordingly existing grade or slope errors are not magnified by a closed loop reaction between the blade and rear wheels which would result in scalloping by employment of the stabilizer system of the present invention. When the
system in FIG. 7 is switched for automatic slope and grade control a slope control system indicated at 128 and a grade control system indicated at 130 becomes active. The specific details of these control systems, shown in block diagram form in FIG. 7, are as described hereinabove in connection with FIGS. 1–3.

Filter circuits 44, 46 integrate the signals produced by stabilizer accelerometers 36 and 38 respectively as previously noted in description re FIGS. 1 and 3. A more detailed arrangement of the integrating filters 44, 46 will be seen in FIG. 4 of the drawings. It will be noted that the signal conditioning circuits between individual stabilizer accelerometers 36, 38 and switch 110 are identical. The output of accelerometer 38 is smoothed by a filter network consisting of a resistor 132 and a capacitor 133 and fed through an operational amplifier 134 which serves as a voltage follower to unload the accelerometer circuitry. The acceleration signal passes from voltage follower 134 through an input resistor 135 to the input of integrating filter 46.

Filter 46 is made up of a first operational amplifier 136, used in an integrating configuration, and a second operational amplifier 137 which serves as a buffer. A capacitor 138 serves as an AC couple between the output of amplifier 136 and the input of amplifier 137. Filter 46 functions to integrate the signal from accelerometer 38, provides an AC couple to buffer amplifier 137 and produces an output velocity signal proportional to acceleration forces sensed by accelerometer 38. The AC couple is needed because the machine frame not always be truly vertical in normal operation. Thus gravity forces acting on the accelerometer mass would cause a steady state DC output which, if integrated, would saturate the system. The AC couple provided by capacitor 138 prevents any signal from reaching the input to amplifier 137 regardless of the disposition of the machine frame from vertical so long as such roll angle is steady state. When the frame roll angle, and hence output from integrating amplifier 136, is changing a signal will be passed by the AC couple provided by capacitor 138 to the input of amplifier 137. The primary purpose of buffer amplifier 137 is to unload the AC couple allowed by capacitor 138.

Accelerometer 38 is disposed on the vehicle frame with its sensitive axis vertical, therefore it will always have a steady state output resulting from the action of gravity on its seismic mass. Such output appears at the input to amplifier 136 which has a particular gain factor dependent upon the values of resistor 139 and capacitor 140 in its feedback circuit and the value of input resistor 135. A biasing voltage is applied at a terminal 141 and a particular value is calculated for a bias resistor 142 to compensate for the steady state acceleration signal thereby controlling the output of amplifier 136 so that no signal will pass through capacitor 138.

A bias network consisting of resistors 143, 144, 145 and 146, connected to the non-inverting input of amplifier 137, serves to compensate for any internal bias of buffer amplifier 137 and assure that it has zero output when no signal is passed by capacitor 138.

Signal conditioning circuitry associated with the right stabilizer accelerometer 36 is identical in function and configuration to the above described circuitry associated with accelerometer 38 for acceleration signals produced by accelerometer 36.

With reference to FIG. 7, switch 110 must be modified and additional filter circuits 44' and 46' must be provided because control circuit instability occurs at a different vehicle speed when operating in the stabilizer mode only than it does when the automatic slope and grade controls (128, 130) are used. This requires that the cut-off frequency of filters 44', 46', i.e., frequency at which acceleration signals are passed, must be different than that of filters 44, 46. This is afforded by identical circuit designs using different values of critical components to give the change in cut-off frequency. Testing has shown that control instability can occur at 1 mph ground speed when using automatic slope and grade controls and at approximately 3 mph when these controls are not in use.

Referring again to FIG. 4, system response is enhanced in the subject control by variable gain features associated with the grade amplifier 70 and slope amplifier 95 that are responsive only to the magnitude of the output of these amplifiers and hence the magnitude of the error signals appearing at their inputs. Amplifier 70 employs a regenerative feedback circuit consisting of diodes 160, 161 and resistor 162. Normally amplifier 70 is biased by a resistor 163 and its output response curve rises gradually for normal error signals. For large grade error signals, however, when the output of amplifier 70 rises above a predetermined level, diode 160 or 161 will conduct, depending upon amplifier output polarity, and the bias for amplifier 70 will be changed to cause its output curve to rise sharply for faster response. Components 160a–163a perform identical functions in the circuit of slope amplifier 95.

Thus it will be seen that the present invention provides a system which stabilizes the blade with respect to the frame and accordingly effectively isolates the blade from the frame. The stabilizer system can be employed in systems wherein slope and grade are maintained manually by the operator or in systems where slope and grade control are effected automatically. The stabilizer system thus enhances the accuracy and speed with which earth surfaces can be smoothed to a desired slope and grade. Because the blade is effectively isolated from the frame, scalloping of the earth surface is virtually eliminated by employment of the present invention. Moreover because the system employs accelerometers as movement sensing devices the system is virtually immune to adverse environmental conditions.

Although two embodiments of the invention have been shown and described, it will be obvious that other adaptations and modifications can be made without departing from the true spirit and scope of the invention. What is claimed is:

1. A system compensating both for roll and pitch in an earth working apparatus with respect to a reference plane, the apparatus being of the type having an elongated frame, support means at the fore and aft ends of the frame for supporting the frame for movement over an earth surface along its longitudinal axis, an earth working blade located between the fore and aft support means, and first and second spaced apart means extending between the blade and the frame for adjustably supporting corresponding spaced apart points of the blade on the frame, said spaced apart means located transversely to the longitudinal axis of the elongated frame so one is on each side thereof, said stabilizing system comprising first and second accelerometers mounted on said frame at transversely spaced apart sites associated with respective said blade supporting means, each said accelerometer including means for
generating an electric signal proportional to the magnitude and direction of the vertical acceleration of the associated frame site, and means operatively connected to said blade supporting means and responsive to respective said electric signal generating means for adjusting respective said points of the blade in a direction opposite the direction of movement of the associated frame site by an amount corresponding to displacement of the associated site so that the position of the blade relative the reference plane remains substantially constant and independent of movement of said frame relative the reference plane.

2. A stabilizing system according to claim 1 wherein each said accelerometer includes a mass, means for constraining said mass for movement along a generally vertical path so that said mass accelerates relative to the frame in response to vertical movement of the frame site, means for confining said mass to a null position on said path in the absence of an acceleration force thereon, means for sensing the displacement of said mass from said null position, means for generating an electric signal having a magnitude proportional to the amount and direction of displacement of said mass from said null position, and means responsive to said electric signal generating means for driving said mass along said path toward said null position.

3. A stabilizing system according to claim 1 wherein said blade supporting means each comprises a vertically extending double acting hydraulic cylinder having fluid inlets at opposite ends thereof, and wherein said blade point adjusting means comprises a source of pressurized hydraulic fluid and an electric-hydraulic valve associated with each said cylinder for controllably valving said fluid to one or the other inlets of the associated cylinder, said valves being responsive to said electrical signal generating means for effecting delivery of fluid to said cylinders at appropriate inlets thereof.

4. A stabilizing system according to claim 1 wherein said earth working apparatus includes a drawbar having a first end, means for securing said first end to said frame for rotatable movement relative thereto, said drawbar having a second end remote from said first end, said blade being mounted to the second end of said drawbar so that the angular position of said blade with respect to vertical determines the angle of the first end of said drawbar with respect to vertical, means associated with said drawbar securing means for producing an electric signal proportional to displacement of said drawbar from said angle, and means for operatively connecting said last said signal to one of said blade adjusting means.

5. A stabilizer system according to claim 4 wherein said signal producing means comprises a shaft journaled for rotation in said frame adjacent said drawbar securing means, means for rotatively positioning said shaft in accordance with the angle of said drawbar relative vertical, and an accelerometer operatively connected to said shaft, said accelerometer producing an electric signal proportional to the rotational component of the drawbar along its longitudinal axis sensed by said accelerometer modified by the angular position of said accelerometer determined by said shaft.

6. A stabilizing system according to claim 5 wherein said accelerometer includes a mass, means for constraining said mass for movement along a path generally arcuate and in a radial plane of said shaft so that said mass accelerates relative shaft in response to rotation of said shaft, means for confining said mass to a null position on said path in absence of an accelerating force thereon, means for sensing displacement of said mass from said null position, means for producing an electric signal having a magnitude proportional to the amount and direction of displacement of said mass from said null position, and means responsive to said electric signal producing means for driving said mass along said path toward said null position.

7. A stabilizing system according to claim 1 including first and second position sensing means for sensing the position of respective said blade supporting means, means combining the output of said position sensing means with respective said electric signal generating means to establish first and second combined signals, means for altering said first and second signals in accordance with the desired orientation of said blade to form first and second altered signals, and means for operatively connecting said altered signals to respective said blade supporting means to afford continuous adjustment thereof.