(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 361 666 A1**

(12) EUROPEAN PATENT APPLICATION

(21) Application number: **89308347.7**

(51) Int. Cl.5 **E02F 9/20 , E02F 9/16**

(22) Date of filing: **17.08.89**

(30) Priority: **08.09.88 US 241654**

(43) Date of publication of application:
04.04.90 Bulletin 90/14

(84) Designated Contracting States:
BE DE FR GB IT SE

(71) Applicant: **CATERPILLAR INC.**
100 Northeast Adams Street
Peoria Illinois 61629-6490(US)

(72) Inventor: **Hadank, John Martin**
12510 Englewood Court
Dunlap Illinois 61525(US)
Inventor: **Allen, William E.**
6927 North Flamingo Court
Peoria Illinois 61614(US)
Inventor: **Bradbury, Walter J.**
7026 North Willow Wood Drive
Peoria Illinois 61614(US)
Inventor: **Anderson, Paul D.**
26206 - 143rd Street, S.E.
Kent Washington 98042(US)

(74) Representative: **Brunner, Michael John et al**
GILL JENNINGS & EVERY 53-64 Chancery Lane
London WC2A 1HN(GB)

(54) Intuitive joystick control for a work implement.

(57) Two multi-axis joysticks (23,24), one horizontal and the other upright, provide the operator of a material handling vehicle with an intuitive control interface to the vehicle (34). The control system (10) also provides a coordinated control for spatial placement of the working device (14) of the work implement (11). Movement up and down and in and out being controlled by the horizontal joystick (23) as is the movement of the working device (14) relative to its adjacent linkage (13). Swinging movement about an upright axis is controlled by the second joystick (24).

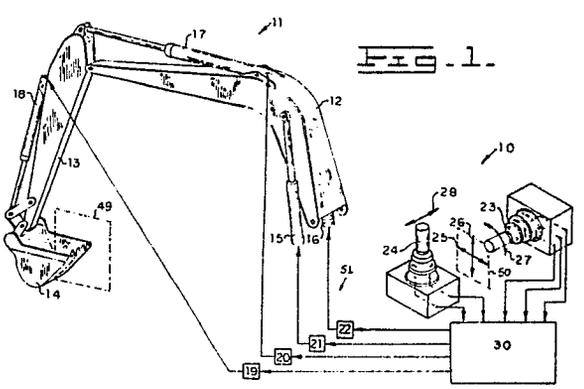


Fig.1.

EP 0 361 666 A1

Intuitive Joystick Control for a Work Implement

This invention relates generally to a control system for controlling a work implement on a work vehicle, and more particularly to a control system which provides an intuitive control interface between the work implement and the vehicle operator.

In the field of work vehicles, particularly those vehicles which perform digging or loading functions such as excavators, backhoe loaders, and front shovels, the work implements are generally controlled with two or more operator controls in addition to other vehicle function controls. The manual control system often includes foot pedals as well as hand operated levers. A backhoe manufactured by J. I. Case Manufacturing Co., for example, employs three levers and two pedals to control the digging implement. A backhoe manufactured by Ford Motor Co. has four levers to control the same. There are serious drawbacks associated with these implement control schemes. One is operator stress and fatigue resulting from having to manipulate so many levers and pedals. A vehicle operator is required to possess a relatively high degree of expertise to manipulate and coordinate the multitude of control levers and foot pedals proficiently. To become productive, an inexperienced operator also requires a long training period to be familiar with the controls and their functions.

Some manufacturers recognize the disadvantages of having too many controls, and have adopted a two-lever control scheme as the norm. Generally, the two vertically mounted two-axis levers share the task of controlling linkages (boom and stick) and the bucket of the work implement. For example, hydraulic excavators presently manufactured by Caterpillar Inc. employ one joystick for stick and swing control, and another joystick for boom and bucket control. Similarly, Deere & Co. has a hydraulic excavator with a joystick for boom and swing control, and another for stick and bucket control. In each instance, the number of controls has decreased to two, making machine operation much more manageable. However, these two-lever control schemes are still not wholly desirable. The assignment of implement linkages to the joysticks is entirely arbitrary, and there exists little correlation between the direction of movement of the work implement linkages and those of the control levers. Thus, to cause the boom to rise, the stick to move toward the vehicle and the bucket to curl as in a typical leveling operation on a Caterpillar hydraulic excavator, the operator manipulates the right-hand joystick diagonally toward the rear and left of the vehicle for bucket curl and boom raise, and the left-hand joystick toward the rear of the vehicle for stick movement.

The desirable correlation of the implement movement intuitively to the controls has only been partially satisfied in known systems.

One such system is described in US-A-4059196. The control system disclosed therein includes a manual control lever in the form of a miniature workimplement consisting of a miniature boom, stick and bucket. To dig, the operator in effect manipulates all three elements of the miniature control implement to go through the same motions as the digging implement. The master-slave control system addresses the problem of correlating the controls to the work implement, but the three-element control lever effectively is a three lever control system that inherently has the same aforementioned multiple control problems. Furthermore, the control system not only does not afford the operator a comfortable grip, it is also awkward to manipulate, position, and coordinate all three elements to mimic the normal course of operations of the boom, stick, and bucket. The control lever is also not of conventional design requiring special manufacture.

Another known system described in US-A-4645030. This discloses a multi-function directional control unit that contains various control levers, switches, and buttons in which each separate control element is associated with a work movement. Although the direction of the human control movements mostly agree with that of the implement movements controlled, the interface constituted by this control unit is not intuitive, nor does it conform to natural expectations. Furthermore, it still requires that the operator become familiar with the one to one mapping of each control element to its respective function, and the multiple control elements easily make operating the machine confusing and demanding. This system is also of special design requiring special manufacture.

The present invention is directed to overcoming the problems set forth above.

It is the primary objective of the instant invention to provide a more intuitive control interface between the operator and the vehicle workimplement. The control elements and the direction and speed of implement movements they control having a logical correlation.

Further objectives are the provision of a control system that is easily manipulable to reduce operator stress and fatigue, and a control system employing control elements of conventional form and design which require no special manufacture.

According to a first aspect of the invention, there is provided a control system for controlling a

work implement on a vehicle, said work implement including a first linkage connected to the vehicle, a second linkage connected to the first linkage, and an working device connected to the second linkage, said linkages, and working device being controllably and pivotally movable in a substantially vertical plane relatively one to the other, and hydraulic actuating means for controlling said first linkage, second linkage and working device in response to control signals from the control system, the control system comprising:
a substantially horizontally disposed joystick movable in first and second directions and rotatable about its longitudinal axis to generate electrical signals corresponding to the movement, and
control means for delivering a plurality of work implement control signals to the hydraulic actuating means in response to receiving the electric signals, whereby vertical motion of the first linkage is controlled by movement of the joystick in the first direction, the horizontal motion of the second linkage is controlled by movement of the joystick in the second direction, and the motion of the working device relative to the second linkage is controlled by the rotational movement of the joystick about its said longitudinal axis.

According to a second aspect of the invention, there is provided a control system for controlling a work implement on a vehicle, said work implement including a first linkage connected to the vehicle, a second linkage connected to the first linkage, and a working device connected to the second linkage, said first linkage, second linkage, and working device being controllably and pivotally movable in a substantially vertical plane relatively one to the other, and hydraulic actuating means for controlling said working device, second linkage and first linkage in response to control signals from the control system, the control system comprising:
a substantially horizontally disposed joystick movable in first and second directions and rotatable about its longitudinal axis to generate electrical signals corresponding to the movement; and
control means for delivering a plurality of work implement control signals to the hydraulic actuating means in response to receiving the electric signals, whereby the vertical motion of the working device corresponds to movement of the joystick in the first direction, horizontal movement of the working device corresponds to movement of the joystick in the second direction, and the control means being operable for coordinating the motions of the linkages and the working device to create a resultant linear motion of the working device.

The instant invention considerably lowers the time required to train an inexperienced operator. In addition, the system is intuitive and not of arbitrary control element-function mapping. The joysticks may be of conventional design and manufacture.

For a better understanding of an example of a control system according to the present invention, reference will now be made to the accompanying drawings, in which:

Fig. 1 is a diagrammatic view of the intuitive joysticks control system and the work implement;

Fig. 2 is an isometric view of the intuitive joysticks control system mounted with respect to the operator seat;

Fig. 3 is a side view of the vehicle performing bucket level motion with phantom lines illustrating implement movement;

Fig. 4 is a block diagram of the coordinated control implementation.

Referring to Fig. 1 a diagrammatic view of an embodiment of the intuitive joystick control system 10 is shown. Vehicles suitable for the application of the instant control system are excavator-type earth-moving or logging machinery, such as excavators, backhoe loaders, front shovels, wheel loaders, track loaders, and skidders (vehicles not shown). The work implement 11 under control typically consists of linkages such as a boom 12 and a stick 13, and working device such as a bucket 14. However, the implement configuration can differ from machine to machine, and the configuration may includea working device other than a bucket, such as a clam shell or grapple. In certain machines, such as the excavator, the operator cab together with the work implement is rotatable along a vehicle center axis; in others, such as a backhoe loader, the operator cab is stationary and the work implement is swingable to a different site at the pivot at the base of the boom. This difference is not significant and the implementation of the intuitive joystick control system in the two cases will be substantially identical.

The work implement 11 of the vehicle is generally actuated in a vertical plane 49, and swingable, with the operator cab, to a plurality of second planes different from the first plane by rotating the vehicle platform or swinging at the pivot base of the boom. The boom 12 is actuated by two hydraulic cylinders 15,16, enabling raising and lowering of the work implement 11. The stick 13 is drawn toward and away from the vehicle by a hydraulic cylinder 17. Another hydraulic cylinder 18 "opens" and "closes" the bucket. The hydraulic flow to the implement cylinders are regulated by hydraulic control valves 21, 22, 20 and 19 respectively.

The operator interface for the control of the work implement consists of two joysticks, one mounted horizontally and the other vertically for easy reach on the right and left hand side of the operator seat. The joysticks are inductive control levers of conventional design such as one manufactured by CTI Electronics of Bridgeport, CT, USA, but other types may also be used. The hori-

zontally mounted joystick 23 has three degrees of movement, all in one plane 50 substantially parallel to work implement plane 49: towards the front and rear of the vehicle (shown by arrow 25), vertically up and down (shown by arrow 26), and rotationally (shown by arrow 27) along its longitudinal central axis 52. The vertically mounted joystick 24 is movable to the left and right of the vehicle (shown by arrow 28). The horizontally mounted joystick 23 generates one signal for each respective degree of movement, each signal representing the joystick displacement direction and velocity from neutral. Similarly, the vertically mounted joystick 24 generates a signal for the left-right displacement direction and velocity for implement side swing control. The electric signals are received by a controller 30, which in response delivers to the hydraulic control valves 19,20,21,22 a plurality of work implement control signals.

Referring now to Fig. 2, an isometric view of the operator seating area and manual controls is shown. The operator, when seated in the seat 31, can rest his or her arms on arm rests 32 where the joysticks 23,24 are within easy reach.

In one embodiment of the instant invention, the joysticks control the work implement linkages independently. In this embodiment, each axis of movement of the horizontally mounted joystick corresponds to a specific linkage on the implement. This is similar to the current conventions of excavator-type machine controls. Thus, the operator is required to compensate for the geometry of the work implement where each linkage follows an arc at each respective pivot point when actuated. In order to keep the bucket level in certain digging operations, for example, the operator has to compensate for the arc by raising and lowering the boom while controlling the stick movement and bucket curl. Although, this embodiment is still more intuitive than conventional designs.

In another and the preferred embodiment, the control of the linkage movements are simultaneously coordinated. Referring to Fig. 3, a vehicle 34 performing bucket level motion is shown. In drawing the bucket level toward the vehicle, all three linkages require simultaneous and coordinated control. In the first phantom outline 35, the stick is out and the bucket is in a closed position. As the implement is drawn to the position shown by the second phantom outline 36, the boom is raised, stick closer to the vehicle, and the bucket in a more open position. At the final position shown by the solid outline 37, the boom is lowered, the stick is drawn in, and the bucket is open. In a vehicle with conventional controls where each linkage is controlled independently, all the linkage motions are explicitly controlled and manipulated by the operator. Since the primary concern of the vehicle operator is the placement of the bucket, the second embodiment of the instant invention allows exact operator displacement and directional control of the bucket regardless of the geometry of the work implement. Therefore, to perform bucket level motion such as in floor finishing, the operator needs only move the horizontally mounted joystick 23 towards the front or rear of the vehicle.

Referring now to Fig. 4, a block diagram of the coordinated control implementation is shown. The electric signals which are generated by the joysticks are shown as joystick velocity request inputs to the block diagram. These velocity request signals are in cartesian coordinates corresponding to the joystick movement. The velocity requests are transformed at 60 to a different coordinate system based on the configuration and position of the linkages. The velocity transformation also receives linkage position data from sensors such as linkage angle resolvers and cylinder position sensors such as known in the art. Please refer to Robot Manipulators: Mathematics, Programming and Control by Richard P. Paul, MIT Press, 1981. The cylinder velocity requests (or joint angular velocity) from this translation process are scaled at block 62 by a factor obtained in the proportional flow control block 61. Proportional hydraulic flow control is discussed in US-A-4712376. The basic concept of the proportional flow control involves calculating for the amount of hydraulic flow available for implement actuation under current operating conditions (i.e.: engine speed, vehicle travel, etc.) The resultant scaled velocity request from block 62 is passed on to velocity control block 63 where an open or closed loop control determines the hydraulic valve velocity control signals to satisfy the cylinder velocity request. Such open or closed loop control systems are well known in the field of control theory. The hydraulic control valve signals are complemented with another set of signals to eliminate errors introduced in the cartesian to linkage coordinate transformation.

Referring now to block 64, the joystick velocity requests are scaled with the same factor obtained in proportional flow control. The scaled joystick velocity commands are integrated over time to obtain position commands 65 and transformed to the linkage coordinates 66. This transformation is similar to that of the transformation process in block 60. The output of position transformation block 66 is then passed on to another open or closed loop control 67 where hydraulic valve position control signal is determined. The hydraulic valve control signals from both branches are combined at 68 to arrived at the final cylinder valve control signals for the work implement.

The cartesian to linkage coordinate transformations discussed above uses the bucket pin as a

reference point and does not take intoconsideration bucket tip position. However, if it is more intuitive for the operator to operate the vehicle with the bucket tip as the significant end point, translation can be easily expanded to accommodate the bucket linkage.

To control the implement, the operator moves the joystick controls as if the implement is an extension of his left and right arms. To cause the implement to move outwards from the vehicle, the operator pushes the right joystick outward towards the front of the vehicle. To cause the implement to move upwards, he raises the right joystick upwards. To cause the bucket to close or curl, he curls his wrist which in turn rotates the right joystick. In one embodiment, the direction and velocity of the implement linkages independently correspond directly to the movement of the joystick controls. In another embodiment, the joystick movements correspond directly to the movement of the bucket. The second embodiment is preferred since it provides the operator direct control of the spatial placement of the bucket at the work location. This is easy to envision if the human arm is likened to the work implement, with pivot points at the shoulder, elbow and wrist. When reaching for an object, the placement and movement of the arm, forearm, and the elbow are of no concern; the concentration is on the placement and path of motion of the hand. The left joystick controls the side swing of the implement to a different work site.

Because the control scheme meets the natural expectations, it should take considerably less time to become familiar and proficient at operating vehicles outfitted with the instant invention. It also reduces the stress and fatigue of the operator, because it takes considerably less concentration to operate.

Claims

1. A control system (10) for controlling a work implement (11) on a vehicle (34), said work implement (11) including a first linkage (12) connected to the vehicle (34), a second linkage (13) connected to the first linkage (12), and a working device (14) connected to the second linkage (13), said linkages (12,13), and working device (14) being controllably and pivotally movable in a substantially vertical plane (49) relatively one to the other, and hydraulic actuating means (51) for controlling said first linkage (12), second linkage (13) and working device (14) in response to control signals from the control system (10), the control system comprising:
a substantially horizontally disposed joystick (23) movable in first and second directions and rotatable about its longitudinal axis to generate electrical signals corresponding to the movement; and
control means (30) for delivering a plurality of work implement control signals to the hydraulic actuating means (51) in response to receiving the electric signals, whereby vertical motion of the first linkage (12) is controlled by movement of the joystick (23) in the first direction (26), the horizontal motion of the second linkage (13) is controlled by movement of the joystick (23) in the second direction (25), and the motion of the working device (14) relative to the second linkage (13) is controlled by the rotational movement (27) of the joystick (23) about its said longitudinal axis (52).

2. A system according to claim 1, wherein said work implement (11) is further simultaneously, controllably, and swingably movable about a substantially vertical axis, further comprising:
an upright second joystick (24) movable in a third direction to generate electric signals corresponding to the movement, and
the control means (30) being arranged to control the swinging motion of the work implement (11) in response to movement of the second joystick in the third direction (28).

3. A system according to claim 1 or claim 2, wherein the control means (30) controls the speed of movement of the first linkage (12), second linkage (13), and working device (14) to be directly proportional to the magnitude of movement of the first and/or second joystick (23,24).

4. A system according to claim 1, 2 or 3, wherein the first linkage (12) is a boom, the second linkage (13) is a stick connected to the boom (12), and the working device is a bucket (14) connected to the stick.

5. A system according to claim 1, or claim 3 or 4 when dependent on claim 1, in which the control means (30) is selectively operable for coordinating the motions of the linkages (12,13) and the working device (14) to create a resultant linear motion of the working device (14).

6. A control system (10) for controlling a work implement (11) on a vehicle (34), said work implement (11) including a first linkage (12) connected to the vehicle (34), a second linkage (13) connected to the first linkage (12), and a working device (14) connected to the second linkage (13), said first linkage (12), second linkage (13), and working device (14) being controllably and pivotally movable in a substantially vertical plane (49) relatively one to the other, and hydraulic actuating means (51) for controlling said working device (14), second linkage (13) and first linkage (12) in response to control signals from the control system (10), the control system comprising:
a substantially horizontally disposed joystick (23) movable in first and second directions and rotat-

able about its longitudinal axis to generate electrical signals corresponding to the movement; and
control means (30) for delivering a plurality of work implement control signals to the hydraulic actuating means (51) in response to receiving the electrical signals, whereby the vertical motion of the working device (14) corresponds to movement of the joystick (23) in the first direction, horizontal movement of the working device (14) corresponds to movement of the joystick (23) in the second direction, and the control means (30) being operable for coordinating the motions of the linkages (12,13) and the working device (14) to create a resultant linear motion of the working device (14).

7. A system according to claim 6, wherein said work implement (11) is further simultaneously, controllably, and swingably movable about a substantially vertical axis, further comprising:
an upright second joystick (24) movable in a third direction to generate electric signals corresponding to the movement, and
the control means (30) being arranged to control the swinging motion of the work implement (11) in response to movement of the second joystick (24) in the third direction (28).

8. A system according to claim 6 or claim 7, wherein the control means (30) controls the speed of movement of the first linkage (12), second linkage (13), and working device (14) to be directly proportional to the magnitude of movement of the first and/or second joystick (23,24).

9. A system according to claim 6, 7 or 8, wherein the first linkage (12) is a boom, the second linkage (13) is a stick connected to the boom (12), and the working device is a bucket (14) connected to the stick.

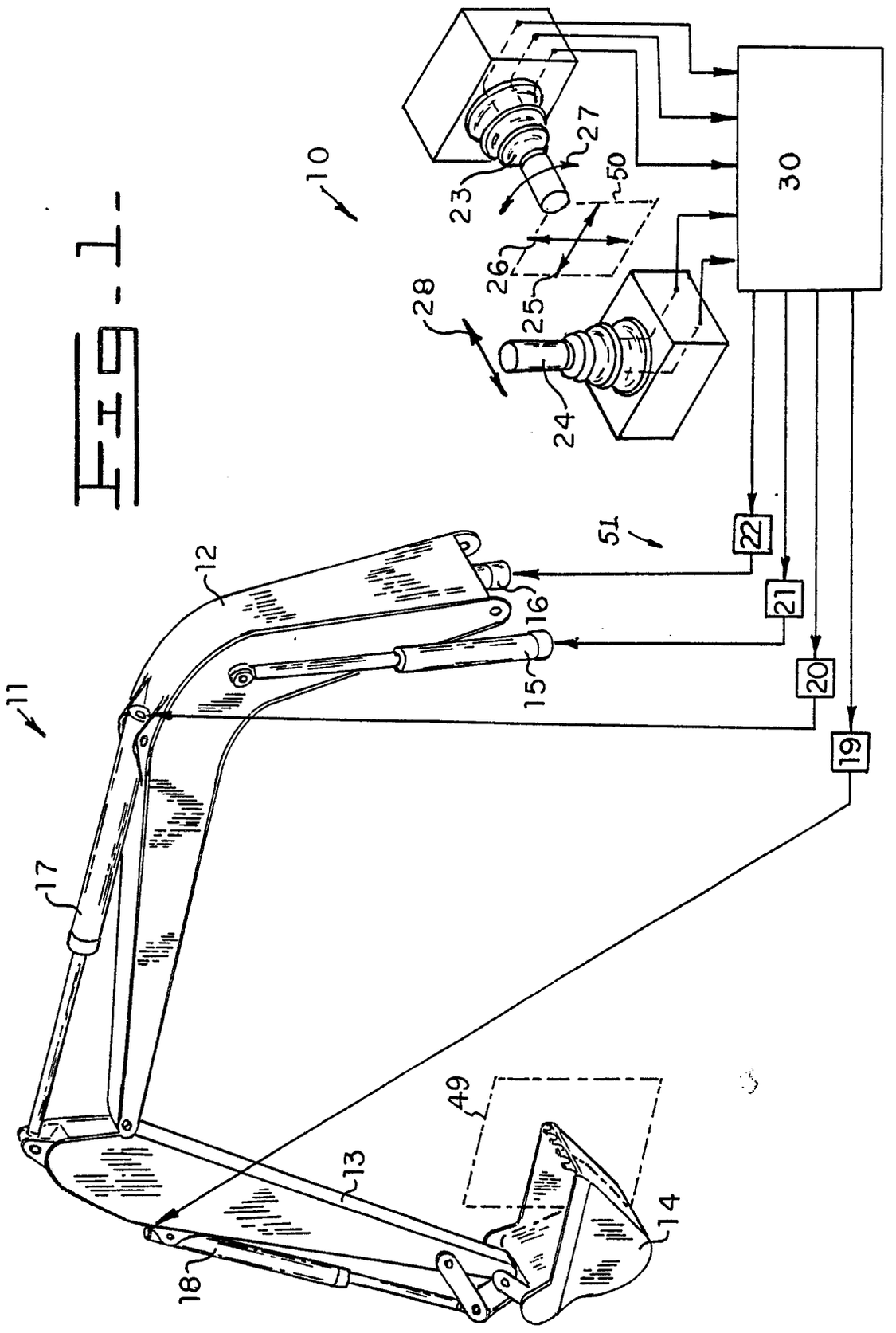


Fig-1-

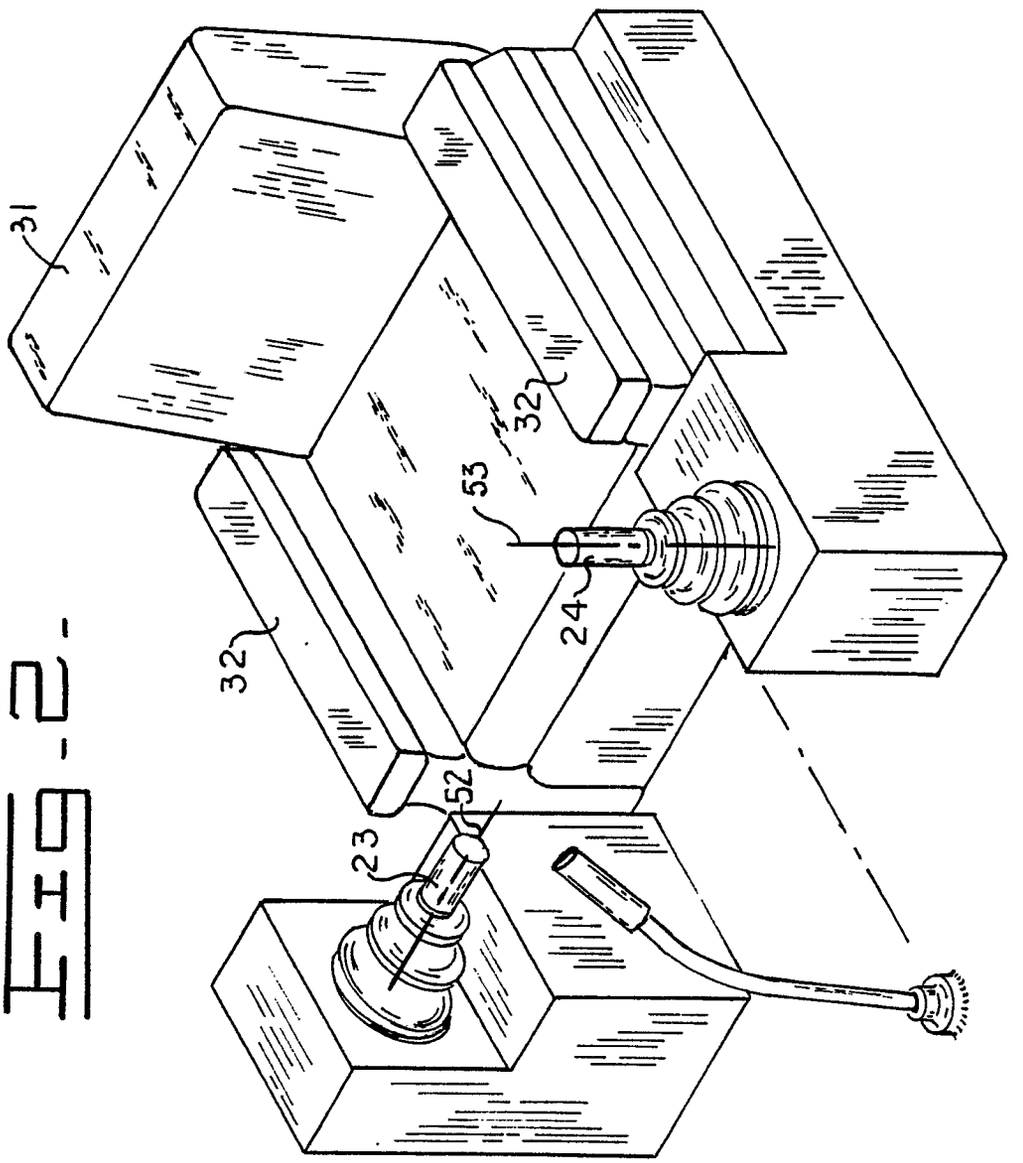
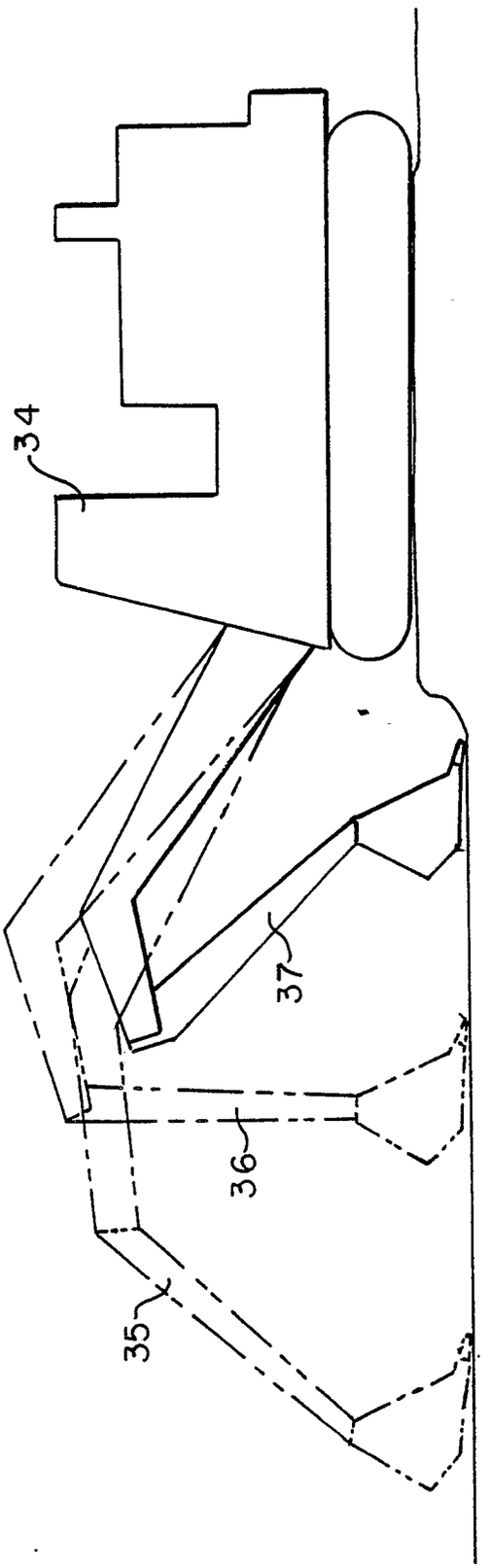


Fig_2_

FIG-3-



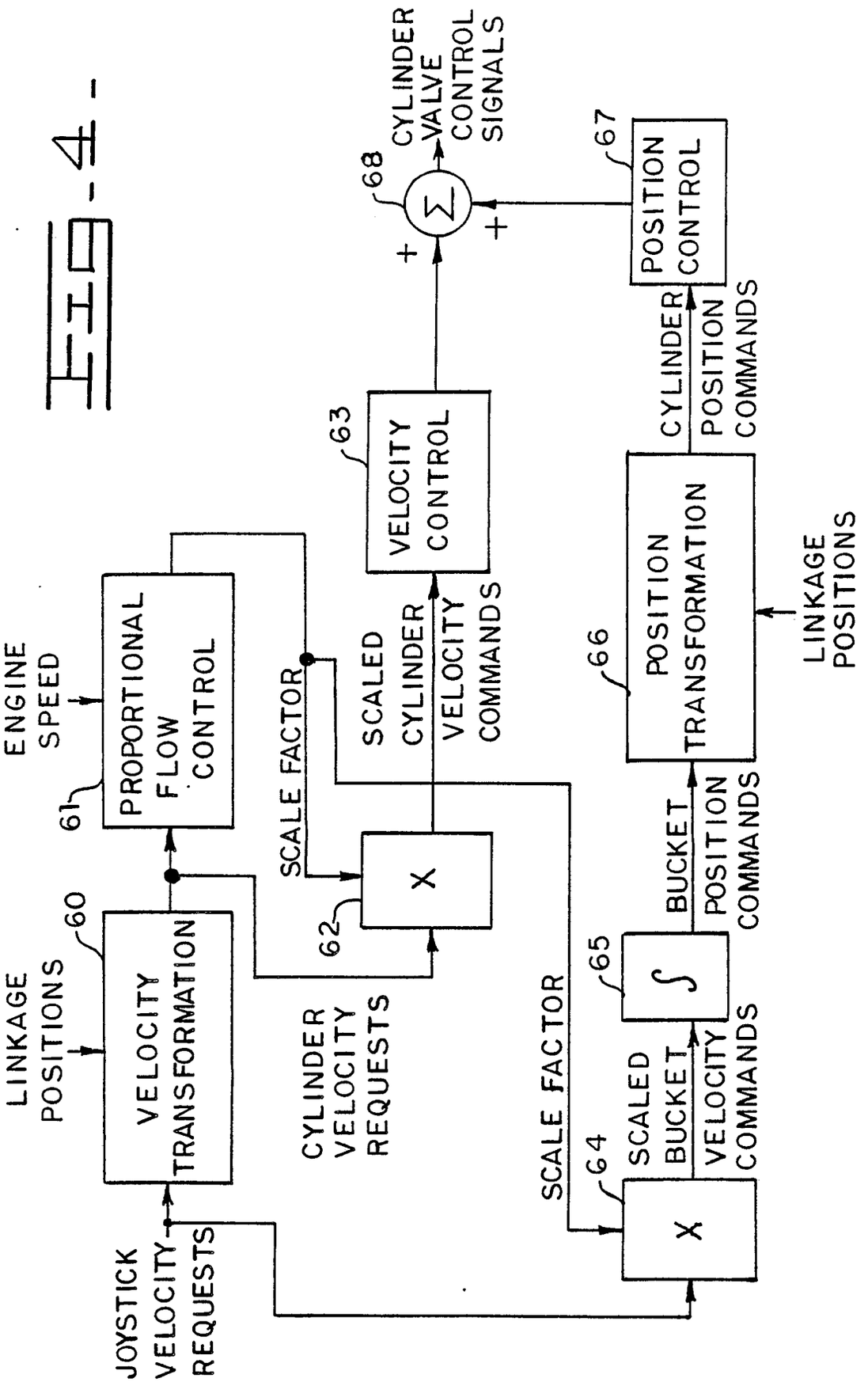

JOYSTICK VELOCITY REQUESTS
LINKAGE POSITIONS
60
VELOCITY TRANSFORMATION
ENGINE SPEED
61
PROPORTIONAL FLOW CONTROL
SCALE FACTOR
62
X
CYLINDER VELOCITY REQUESTS
SCALED CYLINDER VELOCITY COMMANDS
63
VELOCITY CONTROL
68
Σ
+
+
CYLINDER VALVE CONTROL SIGNALS
67
POSITION CONTROL
CYLINDER POSITION COMMANDS
66
POSITION TRANSFORMATION
LINKAGE POSITIONS
SCALE FACTOR
64
X
SCALED BUCKET VELOCITY COMMANDS
65
∫
BUCKET POSITION COMMANDS

FIG-4-

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 89 30 8347

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
A	DE-A-2 230 897 (KNUTSON) * Figure 1 *	1	E 02 F 9/20 E 02 F 9/16
A	FR-A-2 235 014 (SPERRY RAND CORP.) * Claims 1-12; figures 1-5 *	1	
A	FR-A-3 388 821 (W. McKEAN WHITE, Jr.) * Figures 1-3 *	1	

TECHNICAL FIELDS SEARCHED (Int. Cl.5)

E 02 F

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	15-12-1989	ANGIUS P.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P0401)