

Method and apparatus for controlling the loading element
and load of a crane

5 Background of the Invention

10 The invention relates to a method according to
the preamble of claim 1 and a control apparatus
according to the preamble of claim 9 for damping swaying
and skew of the loading element of a crane and the load
attached to it, and for precision positioning the same
in the horizontal direction and in the direction of
skew.

15 Rope-suspended loading elements and loads of
a crane tend to sway when the crane is accelerated or
decelerated. Swaying of the loading element of a
container crane, in particular, is harmful, as the crane
should be able to deposit containers with a relatively
high accuracy.

20 A method and apparatus of the type described
above are known, for example, from Finnish Patent
Application No. 943 401. In this apparatus, the control
of the crane is implemented by a control apparatus
consisting of a mechanism beam comprising three
mechanically interconnected control mechanisms provided
25 with a motor and a brake. The outermost motors of the
mechanism beam comprise double rope drums to which two
auxiliary ropes are always connected in such a manner
that when one auxiliary rope is unwound from the rope
drum, the other auxiliary rope is wound onto it. When
30 swaying is damped and ropes are wound from one drum to
another, the mechanism beam is allowed to move in the
horizontal direction. The mechanism beam can be further
moved in the lateral direction by a third control
mechanism, which is positioned in the middle of the
35 mechanism beam and is connected through gearing to the

mechanism beam without direct connection to the auxiliary ropes.

The control apparatus disclosed in the above-mentioned application is implemented mainly mechanically, and all directions of movement are mechanically bound to each other.

Summary Description of the Invention

The object of the present invention is to improve the method and apparatus for controlling the loading element and load of a crane in order to simplify them mechanically, and to allow the control of each auxiliary rope to be controlled independently but even more accurately and reliably than before, which maximizes the control of the loading element.

This is achieved with a control method of the invention, which is characterized by what is disclosed in the characterizing part of claim 1, and a control apparatus of the invention, which is characterized by what is disclosed in the characterizing part of claim 9.

The present invention is based on the use of four identical but mechanically independent control mechanisms whose control is implemented completely electrically; the control is based on the weighing information of each auxiliary rope and the rotation speed of the motor connected to the auxiliary rope or the drum. There is always a sufficient length of rope in store on a rope drum, which automatically compensates for the different geometry of the auxiliary ropes and the lifting ropes. The forces exerted on each auxiliary rope are adjusted according to instructions given by control logic circuits to prevent the loading element and the load suspended from it from swaying. Both the damping of sway and the precision positioning of the

load can be implemented by means of the control apparatus and its control logic circuits. The mechanically simple solution described above is thus achieved with an electric control system.

5 An essential feature of the invention is the measurement of rope forces of the auxiliary ropes with weighing sensors, and the measurement of the rotation speeds of the motors with tachometers. On the basis of these measurements, target values are calculated for the
10 motor control devices.

 According to the invention, each control logic circuit comprises a force controller for achieving and maintaining a desired rope force, a speed controller based on the rotation speed for counteracting skewing
15 of the rope drum and the shaft of the motor, and a pre-amplifier of the desired rope force for compensating for the effect of force feedback on the moment reference. This sensor arrangement is an essential difference between the present invention and the solution of
20 Finnish Patent Application No. 943 401, where the above-mentioned measurements are not employed.

 The controllers are preferably P-/PD-type controllers, which are special types of PID controllers (PID = proportional + integral + derivative). The
25 controllers can be tuned (the parameters of the controllers can be selected) experimentally or by means of a dynamic model of the system.

Summary Description of the Drawings

30 In the following, the invention will be described in greater detail by means of a preferred embodiment with reference to the accompanying drawings, in which

 Figure 1 shows the general arrangement of the
35 control apparatus of the invention,

Figure 2 shows a control mechanism of the control apparatus, and

Figure 3 is a schematic view of the operating principle of each control mechanism and the control logic circuit connected to it.

Full Description of the Invention

Figure 1 shows a crane 1 and a load 2, e.g. a container, suspended from a loading element 3 of the crane. The loading element 3 is supported by four lifting ropes 4-7 affixed to a first and a second lifting drum 8 and 9 located above the loading element 3 at a distance from each other.

One end of lifting rope 4 is attached to the crane frame 10 at point 11, from which the lifting rope 4 extends to sheave 12 at a first corner of the loading element 3 and then back up to one side of a first lifting drum 8. One end of lifting rope 5 is attached to the crane frame 10 at point 13, from which the lifting rope 5 extends to sheave 14 at a second corner of the loading element 3 and then back up to the other side of the first lifting drum 8.

Correspondingly, one end of lifting rope 6 is attached to the crane frame 10 at point 15, from which lifting rope 6 extends to sheave 16 at a third corner of the loading element 3 and then back up to one side of a second lifting drum 9. One end of lifting rope 7 is attached to the crane frame 10 at point 17, from which the lifting rope 7 extends to sheave 18 at a fourth corner of the loading element 3 and then back up to the other side of the lifting drum 9.

The direction of the lifting ropes 4-7 from the lifting drums 8 and 9 can be perpendicularly downwards, as the damping of sway is implemented by a control apparatus provided with separate inclined auxiliary

ropes. The control apparatus will be described in the following.

5 The control apparatus mounted in the crane damps the sway of the loading element 3 in both horizontal directions X-X' and Z-Z'; it also damps the skew of the loading element. In addition, the control apparatus can be used for precision positioning, i.e. for shifting the loading element 3 over a short distance in both horizontal directions, and also for skewing the loading element clockwise (CW) and counterclockwise (CCW) for a few degrees.

10 The control apparatus comprises four identical control mechanisms 19-22 secured to the crane frame 10 in the middle of the space between the lifting drums 8 and 9, for example, in a rectangular formation such that one mechanism is located at each corner of the rectangle. However, it is not necessary to dispose the control mechanisms 19-22 symmetrically, since asymmetry, when it is known in advance, can be taken into account by means of a control system to be described below. In principle, the control mechanisms 19-22 can thus be placed at the corners of an arbitrary quadrangle. The control system allows the control to be implemented by selecting the desired rope force suitably, whereby the asymmetry of the geometry can be compensated for. The problem with the apparatus disclosed in Finnish Patent Application No. 943 401 is that the control mechanisms must be located very accurately at specific positions, which complicates the layout in other respects. Because of the requirements set by the control mechanisms for the layout, it is difficult to position e.g. the cab in the trolley of the crane.

Each control mechanism (see Figure 2) comprises a rope drum 23 connected through gearing 24 to an electric motor 25, and, between the mechanisms 19-22 and

the loading element 3, four auxiliary ropes 26-29, inclined in relation to the vertical direction. The rope drum 23 is of vital importance to the control apparatus. A length of auxiliary rope 26-29 is stored on it, and the ropes are kept as tight as desired by means of a control system which will be described below. Storing the auxiliary ropes 26-29 on the rope drum 23 automatically compensates for the stretching of the ropes. No separate arrangement or calibration at certain intervals is therefore needed on account of the stretching of the ropes.

The control apparatus also comprises four rope groove sections for the auxiliary ropes 26-29 in the middle of the lifting drums 8 and 9. The lifting drums 8 and 9 and the rope groove sections may be provided with conventional rope grooving, or they may be similar to those described e.g. in Finnish Patent Application No. 943 401.

One end of auxiliary rope 26 is attached to a first rope groove section on the first lifting drum 8. From there the rope extends down to a sheave 30 located in the middle of the first end of the loading element 3 and then back up to the rope drum of the first mechanism 19.

One end of auxiliary rope 27 is attached to a second rope groove section on the first lifting drum 8. From there the rope extends down to a sheave 31 located in the middle of the first end of the loading element 3 and then back up to the rope drum of the second mechanism 20.

One end of auxiliary rope 28 is attached to a first rope groove section on the second lifting drum 9. From there the rope extends down to a sheave 32 located in the middle of the second end of the loading element and then back up to the rope drum of the third mechanism

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One end of auxiliary rope 28 is attached to a second rope groove section on the second lifting drum 9. From there the rope extends down to a sheave 33 located in the middle of the second end of the loading element and then back up to the rope drum of the fourth mechanism 22.

Each control mechanism 19-22 further comprises (see Figure 2) a sensor 34 for weighing the rope force of the auxiliary rope, a tachometer 35 for measuring the rotation speed of the rope drum 23 or the motor 25, and a motor control device 36 (Figure 3) for adjusting the rotation speed (n , Figure 3) or moment of the motor 25 steplessly. If the motors 25 are AC motors, the motor control device 36 may be, for example, an inverter or a frequency converter. Likewise it is naturally possible to use, for example, DC motors, DC actuators or hydraulic actuators; the control system which will be described below does not impose any restrictions on the selection of actuators.

The control apparatus further comprises four identical control logic circuits C (Figure 3) connected to and acting on each mechanism 19-22. On the basis of the rotation speed of each rope drum 23 and the weighing information of each auxiliary rope 26-29, the control logic circuits C control the forces (F , Figure 3) exerted on the auxiliary ropes 26-29 to prevent the loading element 3 from swaying.

As can be seen from Figure 3, each control logic circuit C comprises a force controller C2 for achieving and maintaining a desired rope force, a speed controller C3 for counteracting skewing of the rope drum 23 and the shaft of the motor 25, and a pre-amplifier C1 of the desired rope force for compensating for the effect of force feedback on the moment reference MC. The

subindexes i in Figure 3 indicate the control logic circuit C connected in each case to one of the four identical mechanisms, the motor 25, the motor control device 36, the weighing sensor 34 and the tachometer 35 of the mechanisms 19-22, and the variables relating to the system in use.

The force controller C2 is preferably a PD-controller comprising an amplifying portion and a derivative portion, the P-portion being tuned to be slow in order to implement the desired rope force in a balanced state, and the D-portion being used to change the value of the moment reference MC in dynamic situations. The speed controller C3 is preferably a P-controller which comprises an amplifying portion and is tuned to be fast in order to react sufficiently strongly to dynamic situations.

In the case of symmetrically disposed auxiliary ropes 26-29, the same target values can be given to the forces F_i exerted on each auxiliary rope 26-29 when the sway and skew of the loading element 3 is damped. Thus, in a balanced state $F_i = F_{i\text{ref}}$, i.e. all rope forces F_i are equal, and the rotation speeds n_i of the rope drums 23 are zero.

In the case of asymmetric suspension of auxiliary ropes, the optionally unequal target values set for the forces F_i are such that the horizontal components of the forces F_i compensate each other.

When short shifting movements, or precision positioning, are made in the horizontal direction and in the direction of skew, unequal target values are given to the forces F_i exerted on the auxiliary ropes 26-29. The asymmetric forces of the auxiliary ropes 26-29 thus move the loading element 3 in the desired direction.

The desired tightening $F_{i\text{ref}}$ of the auxiliary

ropes 26-29 can be selected in such a manner that the tightening level is lower with smaller loads than with bigger loads. Thus the mechanisms and motors are loaded as little as possible. The resulting advantages are that the temperature of the motor remains relatively low, and the service life of the mechanisms is lengthened. Furthermore, if the damping property is not utilized, the desired tightening can be selected so that it only keeps the auxiliary ropes 26-29 tight but does not affect the movements of the load 2 and the loading element 3.

In addition, the desired tightening F_{ref} of the auxiliary ropes 26-29 can be selected so that the action of known disturbances (acceleration of shifting movements) is taken into account in advance. Thus it is possible to prepare for a disturbance in advance (e.g. when the shifting movement of the trolley begins) by means of the rope forces (by tightening the auxiliary ropes 26-29 that are on the front side in the direction of acceleration). When the disturbance occurs, the loading element 3 and the load 2 can be kept steady without any sway.

The control sequence of the control logic circuit C can be the moment of the motor 25, which is realized directly by the moment reference MC of a vector-controlled motor control device 36 or, alternatively, as a frequency reference to a scalar-controlled motor control device 36, using feedback to ensure that the desired moment is realized. Moment control can be realized with the same instruments and calculation unit as the rest of the control system; in other words, it does not require any modifications in the apparatus.

The values of the parameters of the control apparatus C are calculated as a function of the lifting

height and the load. The tuning of the parameters is calculated experimentally or by means of a dynamic model of the system.

5 The control system can be implemented by programmable logic (PLC) with floating point number arithmetics. The filtering of measurement signals can be implemented either electrically or by means of software.

10 The method of the invention is active in the sense that it controls the motors 25 of the control mechanisms 19-22 and prevents the sway of the loading element 3 directly on the basis of the available measurement data. The mechanisms 19-22 and the control logic circuits C form an independent unit, wherefore the
15 damping of sway does not affect the operation of the other mechanisms in the crane at all; in other words, the lifting and shifting movements are independent of the operation of the control mechanisms 19-22.

20 It will be obvious to one skilled in the art that the invention is not limited to the working example described above, but it can be modified within the scope of the appended claims. Thus, the definition that the apparatus for controlling the sway is mounted in the crane can also mean that the apparatus is mounted in the
25 trolley of the crane. It is also possible to apply the invention to other cranes than container cranes as long as the auxiliary rope arrangement described above can be implemented therein. In addition to the control system described above, the control mechanisms can also
30 be controlled by another kind of system, e.g. by a discrete-model-based system, in which case the anticipation of disturbances can be implemented optimally. In the case of a discrete-model-based system, it is possible to distinguish between a force controller
35 and a speed controller, but they are not P-/PD-

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controllers in their structure. Furthermore, it should be noted that the invention allows an empty loading element 3 to be suspended by means of the control mechanisms 19-22 from the auxiliary ropes 26-29, whereby maintenance operations of the lifting mechanisms can be performed without a separate support on which the loading element 3 has to be lowered for the maintenance operations.



Claims

1. A method for controlling a loading element (3) suspended from lifting drums (8, 9) of a crane (1) by lifting ropes (4-7), and a load (2) attached to said loading element (3), said controlling referring to damping horizontal (X, X', Z, Z') sway and skew of the loading element (3) and precision positioning the same in the horizontal direction and in the direction of skew (CW, CCW) by the use of a control apparatus comprising control mechanisms (19-22) mounted in the crane and provided with motors (25), and four auxiliary ropes (26-29) between the control mechanisms and the loading element (3), said method comprising controlling the loading element (3) by moving the auxiliary ropes by means of the control mechanisms using four identical mechanisms (19-22) provided with rope drums (23), devices (34) for weighing the rope force and/or tachometers (35) and motor control devices (36), each of said four mechanisms being connected to one auxiliary rope (26-29), and four identical control logic circuits (C) connected to each mechanism for controlling by motors (25) the forces (F) exerted on the auxiliary ropes to prevent the loading element (3) from swaying, characterized in that the motors (25) are controlled on the basis of the rotation speed (n) of each rope drum (23) and the weighing information of each auxiliary rope (26-29) by a control logic circuit (C) comprising a force controller (C2) for achieving and maintaining a desired rope force (F), a speed controller (C3) for counteracting the skewing of the rope drum (23) and the shaft of the motor (25), and a pre-amplifier (C1) of the desired rope force (F) for compensating for the effect of the force feedback on the moment reference (MC).



2. A method according to claim 1, c h a r a c -
t e r i z e d in that, during damping of the sway and
skew of the loading element (3), the same target values
are given to the forces exerted on each symmetrically
disposed auxiliary rope (26-29), whereby all the rope
forces (F) are equal, and the rotation speeds (n) of the
rope drums (23) are zero.

3. A method according to claim 1, c h a r a c -
t e r i z e d in that, during damping of the sway and
skew of the loading element (3), such unequal target
values are given to the forces exerted on the
asymmetrically disposed auxiliary ropes (26-29) that the
horizontal components of the rope forces compensate each
other, whereby the rope forces (F) keep the load and the
loading element in a balanced position, and the rotation
speeds (n) of the rope drums (23) are zero.

4. A method according to claim 1, c h a r a c -
t e r i z e d in that, during short shifting movements,
or precision positioning, in the horizontal direction
and in the direction of skew (AC, CCW), unequal target
values are given to the forces (F) exerted on the
auxiliary ropes (26-29), whereby the asymmetrical forces
of the auxiliary ropes move the loading element (3) in
the desired direction.

5. A method according to claim 1, c h a r a c -
t e r i z e d in that the target values for the forces
(F) exerted on the auxiliary ropes (26-29) are
determined according to the principle of anticipating
control, whereby the target values for the rope forces
can be calculated by means of a dynamic model of the
system to eliminate the known disturbance factors,
typically the accelerations of the shifting movements
of the crane.

6. A method according to claim 1, c h a r a c -
t e r i z e d in that the moment (MC) of the motor is



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used in the control of the control logic circuit (C), said moment being realized directly by the moment control of the vector-controlled motor control device (26).

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7. A method according to claim 1, c h a r a c -
t e r i z e d in that the moment (MC) of the motor is
used in the control of the control logic circuit (C),
said moment being realized as a frequency reference to
a scalar-controlled motor control device (36), using
10 force feedback to ensure that the desired moment is
realized.

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8. A method according to claim 1, c h a r a c -
t e r i z e d in that the tuning of the parameters of
the control logic circuit (C) is calculated by means of
a dynamic model of the system.

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9. An apparatus for controlling a loading
element (3) suspended from lifting drums (8, 9) of a
crane (1) by lifting ropes (4-7), and a load (2)
attached to said loading element (3), said controlling
referring to damping horizontal (X, X', Z, Z') sway and
skew of the loading element (3) and precision
positioning the same in the horizontal direction and in
the direction of skew (CW, CCW), said control apparatus
comprising control mechanisms (19-22) mounted in the
crane and provided with motors (25), and four auxiliary
ropes (26-29) between the control mechanisms and the
loading element (3), whereby the loading element (3) is
controlled by moving the auxiliary ropes by means of the
control mechanisms, said control apparatus comprising
four identical mechanisms (19-22) provided with rope
drums (23), devices (34) for weighing the rope force
and/or tachometers (35) and motor control devices (36),
each of said four mechanisms being connected to one
auxiliary rope (26-29), and four identical control logic
circuits (C) connected to each mechanism for controlling

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the motors (25) to prevent the loading element (3) from swaying, characterized in that each control logic circuit (C) comprises a force controller (C2) for achieving and maintaining a desired rope force (F), a speed controller (C3) for counteracting the skewing of the rope drum (23) and the shaft of the motor (25), and a pre-amplifier (C1) of the desired rope force (F) for compensating for the effect of the force feedback on the moment reference (MC), said control logic circuit (C) being used for controlling the motors on the basis of the rotation speed (n) of each rope drum (23) and the weighing information of each auxiliary rope.

10. An apparatus according to claim 9, characterized in that the force controller (C2) is a PD-controller comprising an amplifying portion and a derivative portion, the P-portion being tuned to be slow in order to implement the desired rope force in a balanced state, and the D-portion being used to change the value of the moment reference (MC) in dynamic situations, and the speed controller (C3) is a P-controller which comprises an amplifying portion and is tuned to be fast in order to react sufficiently strongly to dynamic situations.

11. An apparatus according to claim 9, characterized in that a length of auxiliary rope (26-29) is stored on each rope drum (23) to compensate for the stretching of the auxiliary ropes and the different geometry of the auxiliary ropes and the lifting ropes (4-7).

12. An apparatus according to claim 9, characterized in that an empty loading element (3) can be suspended from the auxiliary ropes (26-29) by means of the control mechanisms (19-22) to allow maintenance operations to be performed without a separate support.

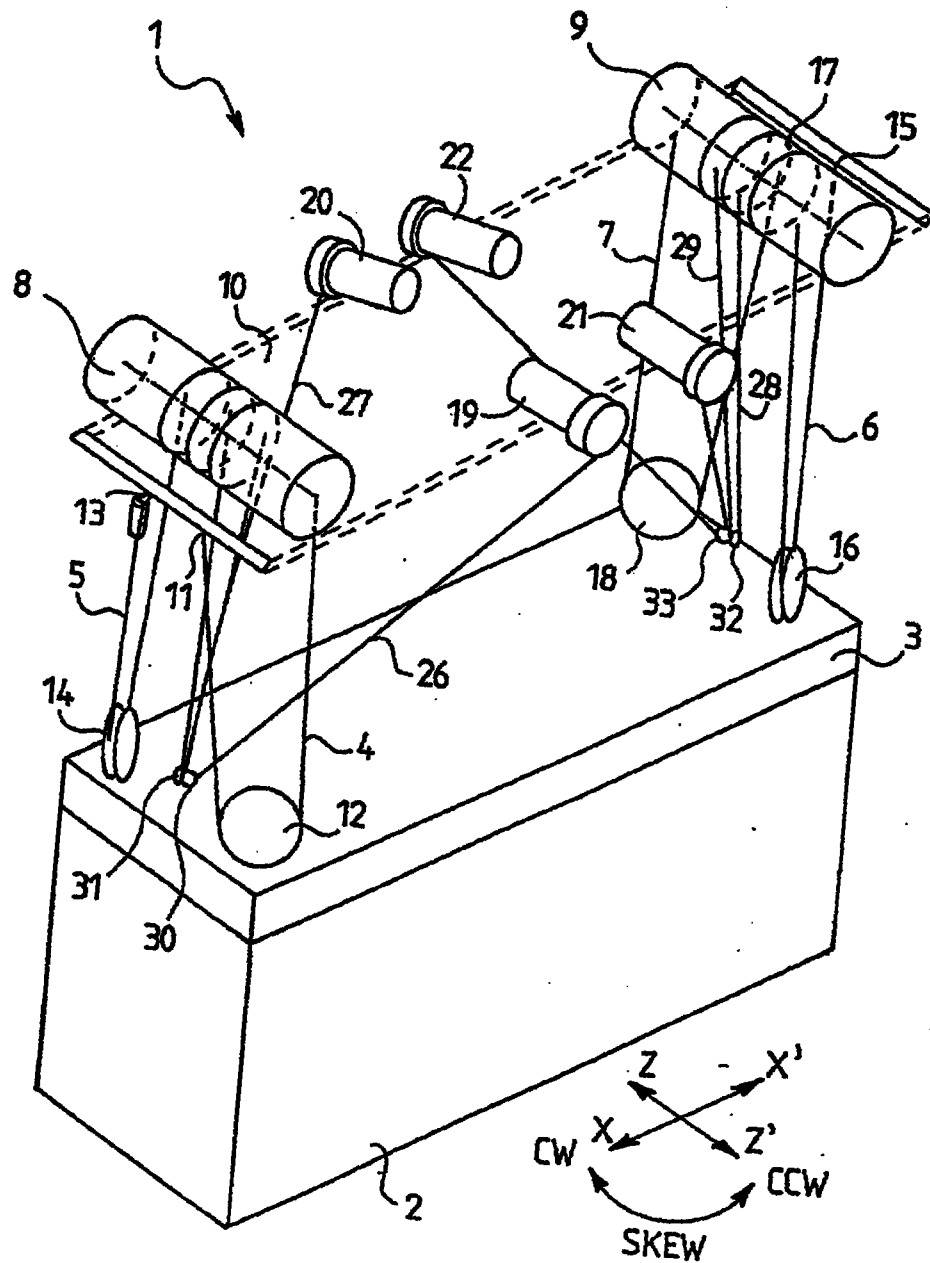


FIG. 1

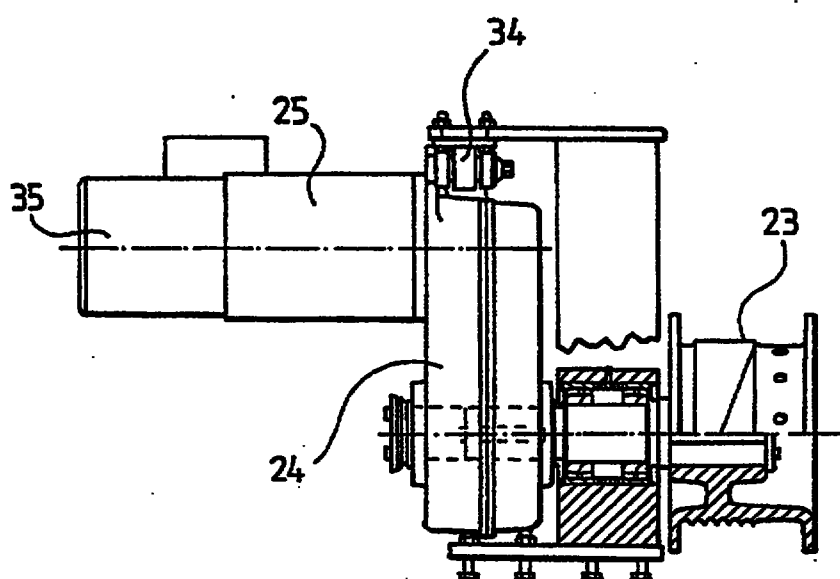


FIG. 2

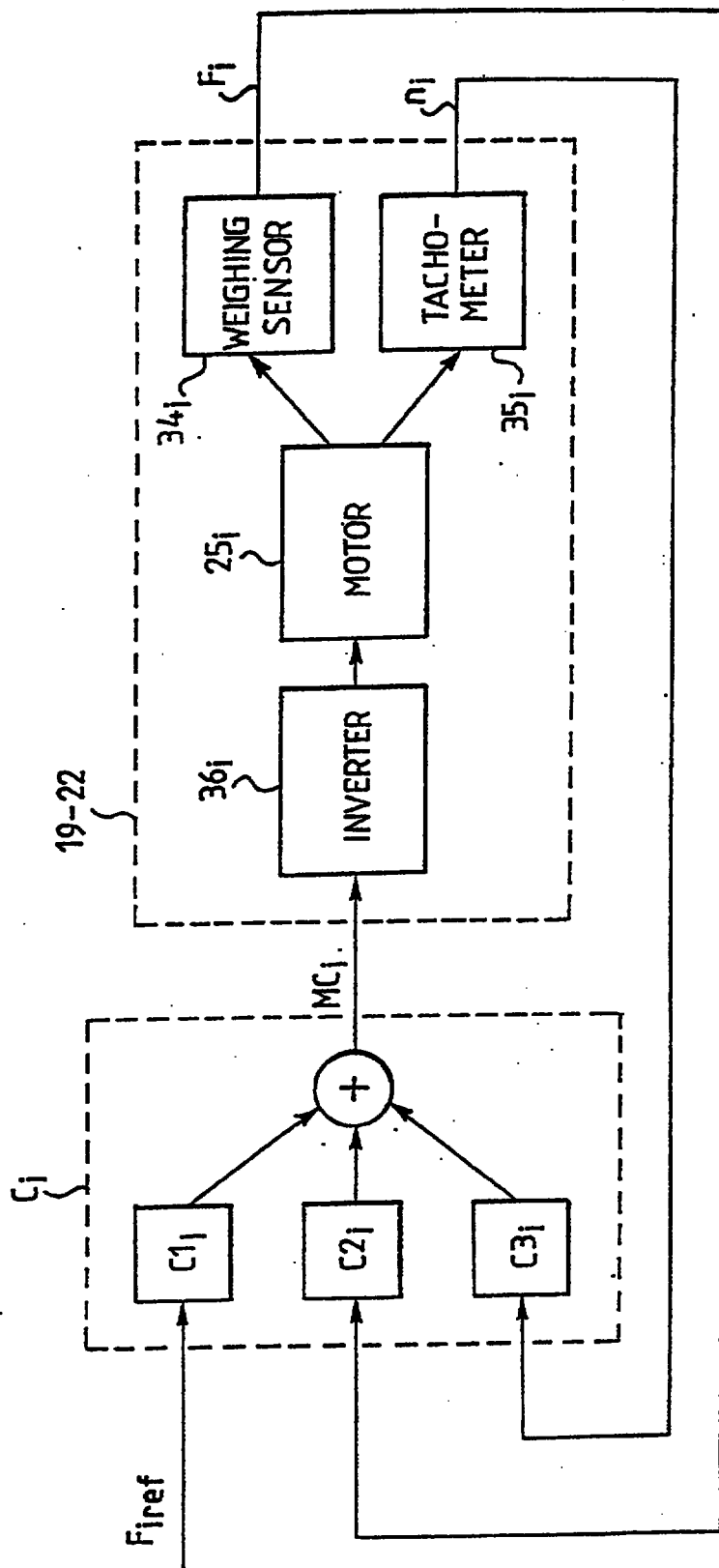


FIG. 3

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used in the control of the control logic circuit (C), said moment being realized directly by the moment control of a vector-controlled motor control device (26).

7. A method according to claim 1, c h a r a c - t e r i z e d in that the moment (MC) of the motor is used in the control of the control logic circuit (C), said moment being realized as a frequency reference to a scalar-controlled motor control device (36), using force feedback to ensure that the desired moment is realized.

8. A method according to claim 1, c h a r a c - t e r i z e d in that the tuning of the parameters of the control logic circuit (C) is calculated by means of a dynamic model of the system.

9. An apparatus for controlling a loading element (3) suspended from lifting drums (8, 9) of a crane (1) by lifting ropes (4-7), and a load (2) attached to said loading element (3), said controlling referring to damping horizontal (X, X', Z, Z') sway and skew of the loading element (3) and precision positioning the same in the horizontal direction and in the direction of skew (CW, CCW), said control apparatus comprising control mechanisms (19-22) mounted in the crane and provided with motors (25), and four auxiliary ropes (26-29) between the control mechanisms and the loading element (3), whereby the loading element (3) is controlled by moving the auxiliary ropes by means of the control mechanisms, said control apparatus comprising four identical mechanisms (19-22) provided with rope drums (23), devices (34) for weighing the rope force and/or tachometers (35) and motor control devices (36), each of said four mechanisms being connected to one auxiliary rope (26-29), and four identical control logic circuits (C) connected to each mechanism for controlling