



## SPECIFICATION

### 1. TITLE OF THE INVENTION

A SWAYING HOISTED LOAD-PIECE DAMPING CONTROL APPARATUS

### 2. FIELD OF THE INVENTION AND RELATED ART STATEMENT

#### 5 (1) Field of the Invention

The present invention relates to a swaying hoisted load-piece damping control apparatus, and more detailedly relates to a swaying hoisted load-piece damping control apparatus for a load-piece hoisting device used in a large-scale load-piece lifting container crane and the like.

#### (2) Description of the Prior Art

Fig.6 shows an overall configuration of a swaying hoisted load-piece damping apparatus for used in a conventional container crane and Fig.7 shows operating states of the conventional swaying hoisted load-piece damping apparatus.

As shown in Fig.6, a transverse trolley 11 is provided transversally movable (movable in the side-to-side directions in Fig.6) on an unillustrated main crane girder. The transverse trolley 11 has a pair of rails 12 and 13 thereon which guide a pair of sheave blocks 14 and 15, respectively so that the sheave blocks 14 and 15 can move within short range in parallel with the moving direction of the transverse trolley 11. The transverse trolley 11 is connected through a wire 16 to a trolley driver 17 disposed on the main girder



(not shown) on which the transverse trolley 11 moves. The sheave blocks 14 and 15 have respective sheave block drivers 18 and 19 for driving the sheave blocks 14 and 15. A hoisting attachment 22 is hanged from the transverse trolley 11 through winding wires 20. This hoisting attachment 22 hoists a container 23 as a hoisted load-piece. Here, as shown in Fig.6, the hoisting attachment 22 has a detecting mark 21 for detecting the sway of the hoisted load-piece.

In stopping the sway of such a load-piece hoisting device, the operator in the operator cab, visually observing the motion of the hoisting attachment 2, used to perform manual remote-control operations in the following manner.

That is, in the state shown in Fig.6, when the trolley drivers 17 drives the transverse trolley 11 from the left to the right in a direction shown by an arrow  $\alpha$ , if the movement of the transverse trolley 11 is changed from the constant-speed transverse travel mode to the retarding travel mode, the hoisted load-piece 23 hanged by the hoisting attachment 22 sways rightward (forward) due to its inertia, as indicated by an arrow  $\beta$  in Fig.7(a). As the operator in the operator cab watches the detecting mark 21 on the hoisting attachment 22 and perceives the sway, the operator controls the transverse trolley 11 to accelerate as indicated by an arrow  $\gamma$  in Fig.7(b), in conformity with the transverse sway of the hoisted load-piece 23 (in the aforementioned direction of the



arrow  $\beta$ ). Alternatively, the two sheave blocks 14, 15 may be controlled to move in the same direction with the swaying direction of the hoisted load-piece 23 by activating the sheave block drivers 18, 19. Thereafter, the operator tries to control the transverse trolley 11 to retard in time with the reverse motion of the hoisted load-piece 23 after the trolley completes a forward-swing of a certain magnitude or should control the sheave blocks 14, 15 to move in the opposite direction to the aforementioned direction so that the transversally swinging load-piece is dampened to stop.

In the case shown in Fig.6, if, for example, the hoisted load-piece 23 slues clockwise causing skew sway on a plane as indicated by arrows A, the operator again perceives it from the movement of the detecting mark 21 and activates the driver 18, 19 so as to move the sheave block 15 leftward (in the direction shown by an arrow B) and the other sheave block 14 rightward (in the direction shown by an arrow C) in synchronism with the skew sway. To deal with a repulsive swing of the hoisted load-piece 23, the sheave blocks 14, 15 may and should be driven in the opposite directions to those described above, so that the skew way is attenuated to stop.

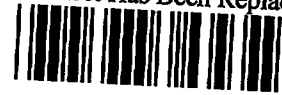
The conventional, swaying hoisted load-piece damping apparatus in which sway is manually stopped by the operator, however, suffers from problems as follows:

That is, as stated above, it is true that simple



transverse sway or simple skew sway of the hoisted load-piece 23 can be attenuated and stopped by the operator by accelerating and/or retarding the transverse trolley 11 or by moving the sheave blocks 14,15 in synchronism with the swinging state of the hoisting attachment 22. But, if transverse sway and skew sway occur at the same time and cause the hoisted load-piece 23 to make a complex motion, it becomes difficult or practically impossible for the operator to manually drive the transverse trolley 11 or the sheave blocks 14, 15 well enough to deal with the situation.

As soon as the hoisted load-piece 23 is stopped to sway, the sheave blocks must normally be returned by force to their home positions or the middle of the transverse trolley 11 with respect to the transverse direction, so that the two (left and right) sheaves 14 and 15 can move in either transverse direction to prepare for a next swing of the hoisted load-piece 23. In order to improve the efficiency of conveying the hoisted load-piece 23, the transverse trolley 11 must be driven at a maximum speed during it travels transversally. When the hoisted load-piece 23 comes near a target position where it is to be unloaded onto the ground, the transverse trolley 11 should be retarded so as to stop at the target position and then need be stopped at the target position where the load-piece is unloaded. To sum up, it is necessary to effect, all at once, position or control of the



sheave blocks 14 and 15, velocity and/or position control of the transverse trolley 11 in conformity with the transverse position and conditions, other than the control of damping the swaying hoisted load-piece 23. Nevertheless, since the conventional sway-damping operation is manually effected by the operator, the controlling operation requires the toughest techniques for even the skilled operators.

### 3. OBJECT AND SUMMARY OF THE INVENTION

The present invention has been achieved to solve the above problems and it is therefore an object of the present invention to provide a swaying hoisted load-piece damping control apparatus which simplifies the operation of damping swaying hoisted load-piece and is able to achieve the damping operation in an assured manner.

Another object of the present invention is to provide a swaying hoisted load-piece damping control apparatus which is able to realize an optimal control for damping and stopping a swaying hoisted load-piece as fast as possible by automating the complicated swaying hoisted load-piece damping operation.

A further object of the present invention is to provide a swaying hoisted load-piece damping control apparatus which is able to improve the work efficiency of conveying hoisted load-pieces by markedly reducing the work amount of the operator and the time required for sway damping.



In order to attain the above objects, a swaying hoisted load-piece damping control apparatus (an apparatus defined in Claim 1) for use in a load-piece hoisting device having a transverse trolley for hoisting a load-piece, and a pair of, or right and left, sheave blocks which are disposed along moving directions of the transverse trolley in parallel with the sides of the transverse trolley and movable relative to the transverse trolley, comprises: trolley moving condition quantity detectors for detecting moving condition quantities of the transverse trolley; hoisted load-piece moving condition quantity detectors for detecting moving condition quantities on right and left sides of the load-piece hoisted by the transverse trolley; sheave-block moving condition quantity detectors for detecting moving condition quantities of the right and left sheave blocks; a notch-driving control quantity detector for detecting transverse notch-driving control quantity of the trolley controlled by means of an operation controlling panel; and a controller for effecting sway-damping control of the load-piece hoisting device based on detection signals obtained from the detectors, and constructed such that the controller has an optimizing control unit which sets up optional controlling quantities for the hoisted load-piece in accordance with moving condition quantities and notch-driving control quantity detected from said detectors, on the basis of a preset



optimal gain for sway damping, and performs sway-damping control by driving said transverse trolley and said sheave blocks in accordance with the setup optimal controlling quantities.

5           According to the present invention, in the swaying hoisted load-piece damping control apparatus defined in Claim 1, the controller comprises: an operating condition determining unit which detects the operating condition of the transverse trolley, based on detected signals of the  
10   operating condition quantities and the notch-driving control quantity for the transverse trolley; an operating-condition-classifying optimal-gain selecting unit which, in accordance with the operating condition detected by the operating condition determining unit, selects an operating-condition-classifying optimal gain for sway damping from a plurality of  
15   predetermined optimal gains; and an optimizing control unit which, based on the optimal gain outputted from the operating-condition-classifying optimal-gain selecting unit, sets up optimal controlling quantities for the hoisted load-piece and performs sway-damping control by driving the  
20   transverse trolley and the sheave blocks in accordance with the setup optimal controlling quantities.

          According to the present invention, in the swaying hoisted load-piece damping control apparatus defined in Claim  
25   1, the controller comprises: an independently controlling



optimal-gain calculating unit which calculates independent optimal gains used to control transverse sway and skew sway of the hoisted load-piece, independently one from the other and outputs the calculated optimal gains; and an optimizing control unit for effecting sway-damping control which, based on the optimal gains outputted from the independently controlling optimal-gain calculating unit, sets up optimal controlling quantities for hoisted load-piece and performs sway-damping control by driving the transverse trolley to damp transverse sway of the load-piece and driving the right and left sheave blocks to damp skew sway of the load-piece.

According to the present invention, in the swaying hoisted load-piece damping control apparatus defined in Claim 1, the controller comprises: an independently controlling optimal-gain calculating unit which calculates independent optimal gains used to control transverse sway and skew sway of the hoisted load-piece, independently one from the other and outputs the calculated optimal gains; an operating condition determining unit which detects the operating condition of the transverse trolley, based on detected signals of the operating condition quantities and the notch-driving control quantity for the transverse trolley; an operating-condition-classifying optimal-gain selecting unit which, in accordance with the operating condition detected by the operating condition determining unit, selects a preset



operating-condition-classifying optimal gain or an operating-condition-classifying optimal gain set up by the independently controlling optimal-gain calculating unit and outputs the selected gain; and an optimizing control unit which, based on the optimal gain outputted from the operating-condition-classifying optimal-gain selecting unit, sets up optimal controlling quantities for the hoisted load-piece and performs sway-damping control by driving the transverse trolley and the sheave blocks in accordance with the setup optimal controlling quantities.

In accordance with the swaying hoisted load-piece damping control apparatus of the present invention, as the container crane is activated, detection signals as to moving condition quantities are detected by the transverse trolley moving condition quantity detector, the right- and left-sheave-block operating condition quantity detectors and the hoisted load-piece moving condition quantity detectors for detecting the movement on right and left sides of the load-piece while the operating quantity signal is detected by the notch-driving control quantity detector. The thus detected signals are sent to the controller. In the controller, an optimal gain for sway damping is previously determined in conformity with the moving condition quantities of the hoisted load-piece such as transverse sway and skew sway during the transverse trolley travels transversally, at the



time of retardation for positioning, or in the stopping state, and then the optimizing control unit effects sway-damping control by driving the transverse trolley and the sheave blocks by optimal controlling quantities set up in accordance with operating condition quantities of the hoisted load-piece on the basis of the optimal gain.

The operating condition determining unit, based on the signals from the transverse trolley moving condition detectors and from the notch-driving control quantity detector, determines which condition the transverse trolley is in, specifically, the condition in which the transverse trolley travels, the condition in which the trolley is retarded for positioning or the condition in which the trolley is stopped with the hoisted load-piece swaying alone. The determined signal is outputted to the operating-condition-classifying optimal gain selecting unit. This operating-condition-classifying optimal gain selecting unit, as receiving the determine signal, selects any one of optimal gains previously set up according to plural classifying operating conditions and outputs the thus selected optimal gain to the optimizing control unit. The optimizing control unit sets up an optimal controlling quantity in accordance with the moving condition quantity of the hoisted load-piece on the basis of the selected optimal gain and drives the transverse trolley and the sheave blocks by the thus set up



by optimal controlling quantities, to thereby perform sway-damping control.

The independently controlling optimal gain calculating unit calculates a required optimal gain for damping  
5 transverse sway and skew sway of the hoisted load-piece so as to output it to the optimizing control unit. The optimizing control unit effects sway-damping control by driving the transverse trolley based on the optimal gain component for damping transverse sway and driving the right and left sheave  
10 blocks based on the optimal gain component for damping skew sway.

The independently controlling optimal gain calculating unit calculates a required optimal gain for damping transverse sway and skew sway of the hoisted load-piece so as  
15 to output it to the operating-condition-classifying optimal gain selecting unit while the operating condition determining unit, based on the signals from the transverse trolley operating condition detectors and from the notch-driving control quantity detector, determines which condition the  
20 transverse trolley is in, specifically, the condition in which the transverse trolley travels, the condition in which the trolley is retarded for positioning or the condition in which the trolley is stopped with the hoisted load-piece swaying alone and outputs the determined signal to the  
25 operating-condition-classifying optimal gain selecting unit.



The operating-condition-classifying optimal gain selecting unit, as receiving these determined signals, selects one of the optical gains classified according to the operating condition and outputs it as an optical gain to the optimizing control unit. The optimizing control unit effects sway-damping control by driving the transverse trolley based on the optimal gain component for damping transverse sway and driving the right and left sheave blocks based on the optimal gain component for damping skew sway.

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#### 4. BRIEF DESCRIPTION OF THE DRAWINGS

Fig.1 is a schematic constructional view showing an overall configuration of a swaying hoisted load-piece damping control apparatus in accordance with an embodiment of the present invention;

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Fig.2 is a block diagram showing a first embodiment of a controlling apparatus;

Fig.3 is a block diagram showing a second embodiment of a controlling apparatus;

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Fig.4 is a block diagram showing a third embodiment of a controlling apparatus;

Fig.5 is a block diagram showing a fourth embodiment of a controlling apparatus;

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Fig.6 is a schematic view showing a conventional swaying hoisted load-piece damping apparatus for use in a



prior art container crane; and

Fig.7 shows illustrations of operating conditions of the conventional swaying hoisted load-piece damping apparatus.

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## 5. DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Embodiments of the present invention will hereinafter be described in detail with reference to Figs.1 through 5.

Fig.1 schematically shows an overall configuration of a swaying hoisted load-piece damping control apparatus in accordance with an embodiment of the present invention. Fig.2 is a controlling block for explaining a first embodiment of a controlling apparatus. In Fig.1, identical reference numerals are allotted to components having the same functions with those in the prior art shown in Fig.6 and repeated description for those is omitted.

As shown in Fig.1, in a controlling apparatus for damping a swaying hoisted load-piece of this embodiment, the trolley driver 17 of the transverse trolley 11 includes a position or displacement detector 31 and a velocity detector 32 as detectors for detecting trolley operating condition quantities. The left-side sheave block 14 is provided with a position or displacement detector 33 and a velocity detector 34 as detectors for detecting moving condition quantities of the sheave block. In the same manner, the right-side sheave

block 15 is provided with a position or displacement detector  
 35 and a velocity detector 36. In order to detect moving  
 condition quantities of the hoisted load-piece, swaying  
 motion detectors 37, 38 are provided respectively on left and  
 5 right sides of the transverse trolley 11 so as to check the  
 motion of the detecting mark 22 on the hoisting attachment 22  
 and thereby detect left-side and right-side swaying positions  
 or displacements and velocities of the hoisted load-piece 23.  
 Further, a transverse operation controlling panel 39 in the  
 10 crane operator cab is equipped with a transverse notch-  
 driving control quantity detector 40.

A controller 41 is to receive detection signals from  
 all the moving condition quantity detectors 31 through 38 and  
 the transverse notch-driving control quantity detector 40  
 15 (see Figs.1 and 2), to calculate optimal controlling  
 quantities required for neutralizing the operating condition  
 quantities inputted, or nullifying the swinging momentum of  
 the hoisted load-piece 23, and to output control command  
 signals to the driver 17 for the transverse trolley 11 and  
 20 drivers 18, 19 for left and right sheave blocks 14, 15.

The controller 41, as shown in Fig.2, has an optimizing  
 control unit 42 which, based on an optimal gain  $K$  for sway  
 damping which is previously calculated and set up separately  
 in the controller 41, determines optimal controlling  
 25 quantities in accordance with the moving condition quantities





of the hoisted load-piece 23 and the operating condition quantities of the transverse trolley 11 supplied from detectors 31 through 38 and 40 and thereby controls the driver 17 of the transverse trolley 11 and drivers 18, 19 for  
5 respective (left and right) sheave blocks 14, 15 so that optimal damping can be done.

Now, description will be made on a specific operational process of sway damping using the swaying hoisted load-piece damping control apparatus of the embodiment described above.

10 (1) First of all, detectors 31 through 38 and 40 detect moving condition quantities of the transverse trolley 11, the sheave blocks 14, 15 and the hoisted load-piece 23 and a transverse notch-driving control quantity and output the detected signals to the controller 41.

15 (2) Next, these moving condition quantities and transverse notch-driving control quantity are used in the optimizing control unit 42 for calculation of optimal sway-damping control to calculate a velocity command  $u_0$  for the transverse trolley 11 and velocity commands  $u_1$ ,  $u_2$  for the sheave blocks  
20 14, 15 by the following formula [1]:

$$u = K \times x \dots [1]$$

Here, 'u' represents a controlling (operating) quantity vector shown as follows and the elements are the velocity command  $u_0$  for the transverse trolley 11, the velocity  
25 command  $u_1$  for the left-side sheave block 14 and the velocity

command u2 for the right-side sheave block 15, in order from the left, and more explicitly, 'u' can be defined as the following equation [2]:

$$u = \begin{bmatrix} u0 \\ u1 \\ u2 \end{bmatrix} \dots [2]$$

A condition quantity vector 'x' is defined as follows. That is, the elements are, in the descending order, a position or displacement x0 and a velocity x1 of the transverse trolley 11, a position or displacement x2 and a velocity x3 of the left sheave block 14, a position or displacement x4 and a velocity x5 of the right sheave block 15, a position or displacement x6 and a velocity x7 of the hoisted load-piece 23 on its left side, and a position or displacement x8 and a velocity x9 of the hoisted load-piece 23 on its right side. Explicitly, 'x' can be expressed as the following equation [3]:

$$x = \begin{bmatrix} x0 \\ x1 \\ x2 \\ x3 \\ x4 \\ x5 \\ x6 \\ x7 \\ x8 \\ x9 \end{bmatrix} \dots [3]$$



A  $3 \times 10$  constant matrix 'K' defined by the following equation [4] represents an optimal gain matrix:

$$5 \quad K = \begin{bmatrix} k_{00} & k_{01} & k_{02} & k_{03} & k_{04} & k_{05} & k_{06} & k_{07} & k_{08} & k_{09} \\ k_{10} & k_{11} & k_{12} & k_{13} & k_{14} & k_{15} & k_{16} & k_{17} & k_{18} & k_{19} \\ k_{20} & k_{21} & k_{22} & k_{23} & k_{24} & k_{25} & k_{26} & k_{27} & k_{28} & k_{29} \end{bmatrix} \dots [4]$$

Here, the constant matrix K as an optimal gain is to be  
10 calculated previously by the following procedures.

1) From the equations of motion for the transverse trolley  
11, the two (left and right) sheave blocks 14, 15 and  
swinging motions on the right and left sides of the hoisted  
load-piece 23, the following equation of state shown by [5]  
15 is derived. This state equation is a liner differential  
equation which represents the swing of the hoisted load-piece  
23 by a spring-mass system of transverse and skew movement.  
Here, detailed description of the state equation, inclusive  
of its derivation, is omitted.

$$20 \quad \dot{x} = A \times x + B \times u \dots [5]$$

where u and x represent the aforementioned controlling  
25 quantity vector and condition quantity vector, respectively,  
while A designates a  $10 \times 10$  constant matrix and B designates  
a  $10 \times 3$  constant matrix.

2) For the above state equation [5], an optimal gain K  
defined as in the following equation [7] is determined so  
30 that an evaluation function J defined by the following



equation [6] takes a minimum value.

$$J = \int_0^{\infty} (x^T \times Q \times x + u^T \times R \times u) dt \quad \dots[6]$$

$$u = K \times x \quad \dots[7]$$

where Q and R represent weighing matrices of 10 x 10 and 3 x 3, respectively.

In this way, by minimizing the evaluation function J, the optimal gain K is to be determined to neutralize or nullify all the elements of the condition quantity x' as fast as possible using the smallest controlling quantity 'u'.

(3) Based on the optimal gain K determined by the above calculation, the optimizing control unit 42 calculates optimal controlling quantities in conformity with the moving condition quantities and the operating condition detected by the detectors 31 through 38 and 40. The thus obtained optimal controlling quantities are outputted to the drivers 17, 18 and 19 for the transverse trolley 11, the two (left and right) sheave blocks 14 and 15, as control command signals for velocity commands u0, u1 and u2, whereby the optimal control for sway damping of the hoisted load-piece 23 is effected.

Fig.3 shows a controlling block representing a second embodiment of a swaying hoisted load-piece damping control

apparatus of the present invention.

As shown in Fig.3, in this embodiment, a controller 51 is composed of: an operating condition determining unit 52 which, receiving detected signals from a transverse notch-driving control quantity detector 40, position and velocity  
5 detectors 31 and 32 of a transverse trolley driver 17, determines the operating condition of a transverse trolley 11 or which condition the transverse trolley 11 is in, specifically, a condition in which the trolley 11 is driven, a condition in which the trolley 11 is in the middle of  
10 retardation to stop at a target place or a condition in which the trolley 11 need sway damping after the positioning, to thereby deliver output signals; an operating-condition-classifying optimal-gain selecting unit 53 which, based on  
15 the signals from the operating condition determining unit 52 and a plurality of operating-condition-classifying optimal gains  $K_1$ ,  $K_2$  and  $K_3$  which are previously calculated and set up for the different operating conditions, selects an optimal gain  $K$  for the detected operating condition from the  
20 operating-condition-classifying optimal gains  $K_1$ ,  $K_2$  and  $K_3$ ; and an optimizing control unit 54 which, receiving the optimal gain  $K$  selected in the operating-condition-classifying optimal-gain selecting unit 53, sets up optimal  
controlling quantities in accordance with moving condition  
25 quantities inputted from the detectors 31 through 38 and





effects optimal control for sway damping by the drivers 17 of the transverse trolley 11, the drivers 18, 19 of respective (left and right) sheave blocks 14, 15.

Now, description will be made on a specific sway-damping process effected by the controller 51 of this embodiment.

(1) The operating condition determining unit 52 determines the operating condition of the transverse trolley 11 based on the detected signals from the transverse notch-driving control quantity detector 40, the position and velocity detectors 31, 32 of the transverse trolley driver 17. At that moment, if the operator is performing a notch-driving operation or the notch-driving operation quantity is not zero, the unit 52 judges that the hoisted load-piece 23 is still far from a target position where the load-piece is to be placed on the ground. When the notch-driving operation quantity becomes equal to zero, the unit 52 judges that the load-piece comes near the target position. When the notch-driving operation quantity is equal to zero and the transverse trolley position information indicates that the load-piece 23 is at the target position with the transverse velocity equal to zero, the hoisted load-piece 23 is judged as to reach the target position.

(2) The operating-condition-classifying optimal-gain selecting unit 53 selects as the optimal gain  $K$  any one of



three optimal gains  $K_1$ ,  $K_2$  and  $K_3$  in accordance with the operating condition determined in (1). Here, the optimal gains  $K_1$ ,  $K_2$  and  $K_3$  are determined in the same manner as described in the procedures 1) and 2) of (2) of the first embodiment, using the following three evaluation functions  $J_1$ ,  $J_2$  and  $J_3$  shown in [8] for the optimal gains  $K_1$ ,  $K_2$  and  $K_3$ , respectively.

$$\begin{array}{lcl}
 10 & J_1 = \int_0^{\infty} (x^T \times Q_1 \times x + u^T \times R \times u) dt & \\
 & J_2 = \int_0^{\infty} (x^T \times Q_2 \times x + u^T \times R \times u) dt & \dots[8] \\
 15 & J_3 = \int_0^{\infty} (x^T \times Q_3 \times x + u^T \times R \times u) dt & \\
 20 & & 
 \end{array}$$

Accordingly, the thus obtained three kinds of optimal gains are classified as  $K_1$ ,  $K_2$  and  $K_3$  in correspondence with  $J_1$ ,  $J_2$  and  $J_3$ , respectively.

Here,  $Q_1$  is a weighing matrix for a velocity following type optimal-gain calculation mode in which the operator effects notch-driving operation in accordance with the velocity of the transverse trolley 11 without effecting positional control of the transverse trolley 11,  $Q_2$  is a weighing matrix for a positional control type optimal-gain calculation mode in which the transverse trolley 11 is controlled so as to reach the target position, and  $Q_3$  is a

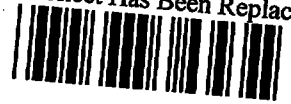


weighing matrix for a sway-damping type optimal-gain  
 ,calculation mode in which the transverse trolley 11 is  
 positioned and sway damping is effected by the sheave blocks  
 14 and 15 alone. R is a constant matrix and may be a unit  
 5 matrix, for instance.

The weighing matrices  $Q_1$ ,  $Q_2$  and  $Q_3$  are represented by  
 the following matrices [9]:

$$Q_1 = \begin{pmatrix} 0 & & & & & & & & & \\ & q_1 & & & & & & & & \\ & & q_2 & & & & & & & \\ & & & q_3 & & & & & & \\ & & & & q_4 & & & & & \\ & & & & & q_5 & & & & \\ & & & & & & q_6 & & & \\ & & 0 & & & & & q_7 & & \\ & & & & & & & & q_8 & \\ & & & & & & & & & q_9 \end{pmatrix}$$

$$Q_2 = \begin{pmatrix} q_0 & & & & & & & & & \\ & q_1 & & & & & & & & \\ & & q_2 & & & & & & & \\ & & & q_3 & & & & & & \\ & & & & q_4 & & & & & \\ & & & & & q_5 & & & & \\ & & & & & & q_6 & & & \\ & & 0 & & & & & q_7 & & \\ & & & & & & & & q_8 & \\ & & & & & & & & & q_9 \end{pmatrix}$$



$$Q_3 = \begin{pmatrix} 0 & & & & & & & & \\ & 0 & & & & & & & \\ & & q_2 & & & & 0 & & \\ & & & q_3 & & & & & \\ & & & & q_4 & & & & \\ & & & & & q_5 & & & \\ & & & & & & q_6 & & \\ & 0 & & & & & & q_7 & \\ & & & & & & & & q_8 \\ & & & & & & & & & q_9 \end{pmatrix} \dots [9]$$

(3) The selection of an optimal gain K by the operating-condition-classifying optimal-gain selecting unit 53 is carried out as follows:

(a) If the load-piece stays far from the target place, the optimal gain  $K_1$  for the velocity following mode in which the operator effects notch-driving operation is selected as the optimal gain K.

(b) If the load-piece is brought close to the target place, the optimal gain  $K_2$  for the positional control mode in which the transverse trolley 11 is controlled so as to reach the target place is selected as the optimal gain K.

(c) If the load-piece is positioned at the target place, the optimal gain  $K_3$  for the sway-damping mode in which sway is damped by the sheave blocks 14 and 15 alone is selected as the optimal gain K.

(4) Then, in the same manner as in the first embodiment, the moving condition quantities and the transverse notch-driving control quantity detected by the detectors 31 through



38 and 40 are outputted to the controller 51.

(5) From the operating condition inputted, the controller 51 makes the optimizing control unit 54 effect the calculation of sway-damping optimizing control based on the  
5   aforementioned equation [1] to determine the velocity command  $u_0$  for the transverse trolley 11 and velocity commands  $u_1$  and  $u_2$  for respective sheave blocks 14 and 15.

(6) The optimizing control unit 54, based on the optimal gain  $K$ , calculates optimal controlling quantities in  
10   conformity with the moving condition quantities and the operating condition detected by the detectors 31 through 38 and 40 and outputs the obtained optimal controlling quantities as control command signals for velocity commands  $u_0$ ,  $u_1$  and  $u_2$  to the drivers 17, 18 and 19 for the transverse  
15   trolley 11 and the two (left and right) sheave blocks 14 and 15, whereby the hoisted load-piece 23 is optimally controlled to stop swinging.

Thus, in accordance with the controller 51 described in the second embodiment, it is possible to eliminate the  
20   difficulties in the operating-condition classifying determination and the operation control in the conventional configuration by determining the operating condition of the transverse trolley 11 by the operating condition determining unit 52, allowing the operating-condition-classifying  
25   optimal-gain selecting unit 53 to select an individual



optimal gain K for each mode selected from the velocity following mode, the target-position reaching mode and the sway-damping mode using the sheave blocks 14 and 15, in correspondence with the operation condition of the transverse trolley 11, and making the optimizing control unit 54 effect optimal control of damping sway based on the selected optimal gain K.

Fig.4 shows a control block representing a third embodiment of a swaying hoisted load-piece damping control apparatus of the present invention.

As shown in Fig.4, a controller 61 of the present invention is composed of an optimal-gain calculating unit 62 for independently controlling transverse sway and skew sway in order to calculate optimal gains which are used when the transverse sway and skew sway are damped independently each from the other and an optimizing control unit 63 for effecting sway-damping control based on the optimal gain K determined by the resulting calculation in the optimal-gain calculating unit 62 for independently controlling transverse sway and skew sway. When both transverse and skew sway are detected simultaneously through the aforementioned detectors 31 through 38 and 40, the optimizing control unit 63 is to set up, in accordance with the detection, separate optimal controlling quantities for the transverse trolley driver 17 for damping the transverse sway and for the two (left and



right) sheave block drivers 18 and 19 for damping the skew sway based on the optimal gain K determined by the optimal-gain calculating unit 62 for independently controlling transverse sway and skew sway and thereby effect the damping control separately.

Now, description will be made on a specific flow of sway damping by the controller 61 of this embodiment.

(1) The optimal-gain calculating unit 62 for independently controlling transverse sway and skew sway calculates an optimal gain in the following way:

1) In the state equation [5] shown above, if  $x$  is substituted by  $x = T \times x'$  to effect a mode transformation, then the following state equation [10] can be obtained. Here,  $x'$  and  $T$  indicate a new condition quantity vector and a mode transforming matrix, respectively.

$$\dot{x}' = A' \times x' + B' \times u \quad \dots[10]$$

where  $A' = T^{-1} \times A \times T$        $B' = T^{-1} \times B$

$$x' = \begin{pmatrix} x_0 \\ x_1 \\ x_2' \\ x_3' \\ x_4' \\ x_5' \\ x_6' \\ x_7' \\ x_8' \\ x_9' \end{pmatrix}$$



$$T = \begin{pmatrix} 1 & & & & & & & & & \\ & 1 & & & & & & & & \\ & & 10 & 10 & & & & & & 0 \\ & & 01 & 01 & & & & & & \\ & & 10 & -10 & & & & & & \\ & & 01 & 0 & -1 & & & & & \\ & & & & & 10 & 10 & & & \\ & 0 & & & & 01 & 01 & & & \\ & & & & & 10 & -10 & & & \\ & & & & & 01 & 0 & -1 & & \end{pmatrix}$$

In one word, a new state equation is derived with respect to a new condition quantity vector  $x'$  whose elements are: in the descending order,  $x_0$  and  $x_1$ : position or displacement and velocity of the transverse trolley 11;  $x_2'$  and  $x_3'$ : transverse components of the position or displacement and velocity of the sheave blocks 14, 15;  $x_4'$  and  $x_5'$ : skew components of the position or displacement and velocity of the sheave blocks 14, 15;  $x_6'$  and  $x_7'$ : transverse components of the position or displacement and velocity of the hoisted load-piece 23; and  $x_8'$  and  $x_9'$ : skew components of the position or displacement and velocity of the hoisted load-piece 23.

2) For the above state equation [10], an optimal gain matrix  $K'$  defined as in the following equation [12] is determined so that an evaluation function  $J$  defined by the following equation [11] takes a minimum value.



$$J = \int_0^{\infty} (x'^T \times Q \times x' + u^T \times R \times u) dt \quad \dots[11]$$

5

$$u = K' \times x' \quad \dots[12]$$

10 where  $Q$  and  $R$  represent weighing matrices of  $10 \times 10$  and  $3 \times 3$ , respectively. Explicitly,  $Q$  can be expressed as follows:

$$Q = \begin{pmatrix} q_0 & & & & & & & & & \\ & q_1 & & & & & & & & \\ & & q_2 & & & & & & & \\ & & & q_3 & & & & & & 0 \\ & & & & q_4 & & & & & \\ & & & & & q_5 & & & & \\ & & & & & & q_6 & & & \\ & & & & & & & q_7 & & \\ & & & & & & & & q_8 & \\ & & & & & & & & & q_9 \end{pmatrix}$$

15

20

25 In this way, by minimizing the evaluation function  $J$ , the gain optimal matrix  $K'$  is to be determined to neutralize or nullify all the elements of the condition quantity  $x'$  as fast as possible using the smallest controlling quantity.

Here, the optimal allocation of tasks to the transverse  
30 trolley and the sheave blocks should be determined in order to achieve optimal control of sway damping. This depends on the setup of the weighing matrix  $Q$  appearing in the above equation [11].

Sway of the hoisted load-piece 23 during the transverse  
35 travel qualitatively comprises a large transverse swinging



motion, generated due to the inertial of the hoisted load-piece 23 when it is accelerated or retarded and a skew swinging motion relatively smaller than the transverse swinging motion, generated due to the eccentricity etc., of the hoisted load-piece 23. In order to damp the relative large transverse swinging motion, optimal control of sway damping by the transverse trolley 11 should be used since the movement of the sheave blocks 14, 15 is limited within a short stroke on the transverse trolley 11 and therefore can not deal with the large swinging motion. On the other hand, in order to damp the skew swinging motion, optimal control of sway damping by the sheave blocks 14 and 15 should be applied since the skew sway is relatively small and the movement of the transverse trolley 11 can not deal with this kind of motion, theoretically.

This allocation of tasks can be achieved by adjusting elements of the weighing matrix  $Q$ , specifically,  $q_2$ ,  $q_3$ ,  $q_4$  and  $q_5$  as follows:

The elements  $q_2$  and  $q_3$  are the weighing coefficients of the transverse movement component for the sheave blocks 14, 15, and if these elements are taken large, the transverse motion of the sheave blocks 14 and 15 required for damping transverse swinging motion will be limited. Therefore, only the trolley 11 will contribute to controlling the damping operation of transverse swinging motion.



The elements  $q_4$  and  $q_5$  are the weighing coefficients of the skew movement component for the sheave blocks 14, 15, and if these elements are taken small, the movement of the sheave blocks 14 and 15 required for damping skew swinging motion can be secured within the stroke ranges of the sheave blocks 14 and 15. Further, since the transverse trolley 11 cannot contribute to the skew movement theoretically, only the sheave blocks will effectively control the damping operation of skew swinging motion.

3) Next, with  $x = T^{-1} \times x$  substituted in the above equation [12], the following equation [13] can be obtained. This allows the system to obtain an optimal gain  $K = K' \times T^{-1}$  for the feed-back condition quantity  $x$ .

$$u = K' \times T^{-1} \times x = K \times x \quad \dots[13]$$

The optimal gain thus obtained by the above calculation is set up as an optimal gain part K.

(2) Then, in the same manner as in the first embodiment, the moving condition quantities and the transverse notch-driving control quantity detected by the detectors 31 through 38 and 40 are outputted to the controller 61.

(3) From the moving condition quantities and transverse notch-driving control quantity inputted, the controller 61 makes the optimizing control unit 63 effect the calculation of sway-damping optimizing control based on the aforementioned equation [1] to determine the velocity command



u0 for the transverse trolley 11 and velocity commands u1 and u2 for respective (left and right) sheave blocks 14 and 15.

(4) The optimizing control unit 63, based on the optimal gain K, calculates optimal controlling quantities in conformity with the moving condition quantities and operating condition detected by the detectors 31 through 38 and 40 and outputs the obtained optimal controlling quantities as control command signals for velocity commands u0, u1 and u2 to the drivers 17, 18 and 19 for the transverse trolley 11 and the two (left and right) sheave blocks 14 and 15, whereby the hoisted load-piece 23 is optimally controlled to stop swinging.

Thus, with the controller 61 illustrated in the third embodiment, the condition quantity vector x obtained from the detectors 31 through 38 and 40 is multiplied by the mode transforming matrix  $T^{-1}$  to produce a new condition quantity vector x' in which the transverse swinging component and the skew swinging component are separated. The thus newly produced vector x' is multiplied by the optimal gain K' to obtain optimal controlling quantity vector u. As to the damping operation, the optimizing control unit 63 is constructed such that the transverse swinging component is damped by the drive of the transverse trolley 11 while the skew swinging component is damped by the drive of the sheave blocks 14 and 15. In the prior art system, it was very



difficult for the operator to designate how to control the transverse trolley 11 and/or the sheave blocks 14, 15, but it is possible for this embodiment to solve the conventional problem of this kind.

5           Fig.5 shows a control block representing a fourth embodiment of a swaying hoisted load-piece damping control apparatus of the present invention.

          As shown in Fig.5, a controller 71 of this embodiment is has combined features of the controllers 51 and 62  
10       described in the second and third embodiments.

          Specifically, in the controller 71, an optimizing control unit 72, as receiving detection signals from the detectors 31 through 38 and 40, sets up optimal controlling qualities always referring to an optimal gain  $K$  which is  
15       determined according to both the operating condition and swinging modes (i.e., the transverse swinging motion and the skew swinging motion) as executed in the controllers 51 and 61 of the second and third embodiments. With the thus determined optimal controlling quantities, the controller 71  
20       effects sway-damping control.

          Now, description will be made on a specific sway-damping process effected by the controller 71 of this embodiment.

(1)       In the same manner as in the above-described third  
25       embodiment, the optimal-gain calculating unit 62 for



independently controlling transverse sway and skew sway derives the aforementioned state equation [10]. Then, optimal gains  $K_1$ ,  $K_2$  and  $K_3$  are determined in the same manner as described in the second embodiment, so that the

5      aforementioned three evaluation functions  $J_1$ ,  $J_2$  and  $J_3$  shown in [8] may be minimized. Here, weighing matrices  $Q_1$ ,  $Q_2$  and  $Q_3$  use those shown in the second embodiment. As to  $Q_1$  and  $Q_2$ ,  $q_2$ ,  $q_3$ ,  $q_4$  and  $q_5$  should be adjusted as shown in the third embodiment, so that the optimal gains  $K_1$  and  $K_2$  should allow

10     independent control operations, that is, control of the trolley 11 for transverse sway and control of the sheave blocks 14, 15 for skew sway can be done independently.

(2)    As the following procedures are effected in the same manner as in the second embodiment, the detailed description

15     is omitted.

Thus, with the controller 71 illustrated in the fourth embodiment, the condition quantity vector  $x$  obtained from the detectors 31 through 38 and 40 is multiplied by the mode transforming matrix  $T^{-1}$  to produce a new condition quantity

20     vector  $x'$  in which the transverse swinging component and the skew swinging component are separated. The thus newly produced vector  $x'$  is multiplied by the optimal gain  $K'$  to obtain an optimal controlling quantity vector  $u$ . As to the damping operation, the optimizing control unit 72 is

25     constructed such that the transverse swinging component is



damped by the drive of the transverse trolley 11 while the skew swinging component is damped by the drive of the sheave blocks 14 and 15. In the prior art system, it was very difficult for the operator to designate how to control the transverse trolley 11 and/or the sheave blocks 14, 15, but it is possible for this embodiment to fix the conventional problem of this kind.

Further, it is possible to eliminate the difficulties in the operating-condition classifying determination and the operation control in the conventional configuration by determining the operating condition of the transverse trolley 11 by the operating condition determining unit 52, allowing the operating-condition-classifying optimal-gain selecting unit 53 to select an individual optimal gain  $K$  for each mode selected from the velocity following mode, the target-position reaching mode and the sway-damping mode using the sheave blocks 14 and 15, in correspondence with the operating condition of the transverse trolley 11, and making the optimizing control unit 72 effect optimal control of damping sway based on the selected optimal gain  $K$ .

As has been described in detail referring to the embodiments, the first feature of the swaying hoisted load-piece damping control apparatus of the present invention is equipped with a transverse trolley having a pair of sheave blocks which are disposed on both sides of the transverse



trolley and movable relative to the transverse trolley and further comprises: different kinds of detectors such as for detecting moving condition quantities of the transverse trolley, detecting moving condition quantities on right and left sides of the load-piece and detecting moving condition quantities of the right and left sheave blocks; a transverse notch-driving control quantity detector provided on an operation controlling panel; and a controller for effecting sway-damping control of a load-piece hoisting device based on detection signals obtained from the detectors, and is constructed such that the controller has an optimizing control unit which sets up optimal controlling quantities for the hoisted load-piece in accordance with moving condition quantities and notch-driving control quantity detected from the detectors, on the basis of a preset optimal gain for sway damping, and performs sway-damping control by driving the transverse trolley and the sheave blocks by the setup optimal controlling quantities. Therefore, it is possible to establish easy sway-damping control of the hoisted load piece in an assured manner by automating the sway-damping control of the hoisted load-piece which has been difficult in the prior art. Further, it is possible to realize the optimal sway-damping control which can damp the sway of the hoisted load-piece as fast as possible and to inhibit the load-piece from swinging. As a result, the work amount of the operator



as well as the time required for sway damping can be markedly decreased, thereby making it possible to improve the conveying efficiency of hoisted load-pieces.

5 In accordance with the second feature of the swaying  
hoisted load-piece damping control apparatus of the present  
invention, the controller comprises: an operating condition  
determining unit which detects the operating condition of the  
transverse trolley, based on detected signals of the  
operating condition quantities and the notch-driving control  
10 quantity for the transverse trolley; an operating-condition-  
classifying optimal-gain selecting unit which, in accordance  
with the operating condition detected by the operating  
condition determining unit, selects an operating-condition-  
classifying optimal gain for sway damping; and an optimizing  
15 control unit which, based on the optimal gain outputted from  
the operating-condition-classifying optimal-gain selecting  
unit, sets up optimal controlling quantities for the hoisted  
load-piece and performs sway-damping control by driving the  
transverse trolley and the sheave blocks in accordance with  
20 the setup optimal controlling quantities. Therefore, it  
becomes possible to set up an optimal gain by surely  
determining the operating condition of the trolley as to be  
in a state of the transverse travel, in a state of retarding  
travel or in a state of stopping and requiring sway-damping  
25 operation. As a result, it is possible to simplify the



determination of the operating condition and its operating control.

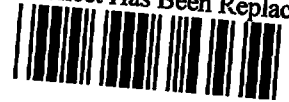
In accordance with the third feature of the swaying hoisted load-piece damping control apparatus of the present invention, the controller comprises: an independently  
5 controlling optimal-gain calculating unit which calculates independent optimal gains used to control transverse sway and skew sway of the hoisted load-piece, independently one from the other and outputs the calculated optimal gains; and an  
10 optimizing control unit for effecting sway-damping control which, based on the optimal gains outputted from the independently controlling optimal-gain calculating unit, sets up optimal controlling quantities for hoisted load-piece and effects sway-damping control by driving the transverse  
15 trolley to damp transverse sway of the load-piece and driving the right and left sheave blocks to damp skew sway of the load-piece. Therefore, it becomes possible to damp and inhibit the transverse sway and skew sway of the hoisted load-piece separately one from the other, and consequently,  
20 it is possible to establish proper control of driving the transverse trolley and sheave blocks in order to effect optimal sway-damping.

In accordance with the fourth feature of the swaying hoisted load-piece damping control apparatus of the present  
25 invention, the controller comprises: an independently



controlling optimal-gain calculating unit which calculates independent optimal gains used to control transverse sway and skew sway of the hoisted load-piece, independently one from the other and outputs the calculated optimal gains; an  
5 operating condition determining unit which detects the operating condition of the transverse trolley, based on detected signals of the operating condition quantities and the notch-driving control quantity for the transverse trolley; an operating-condition-classifying optimal-gain  
10 selecting unit which, in accordance with the operating condition detected by the operating condition determining unit, selects a preset operating-condition-classifying optimal gain or an operating-condition-classifying optimal gain set up by the independently controlling optimal-gain  
15 calculating unit and outputs the selected gain; and an optimizing control unit which, based on the optimal gain outputted from the operating-condition-classifying optimal-gain selecting unit, sets up optimal controlling quantities for the hoisted load-piece and performs sway-damping control  
20 by driving the transverse trolley and the sheave blocks in accordance with the setup optimal controlling quantities. Therefore, it becomes possible to set up an optimal gain in accordance with the operating condition of the transverse trolley and the swinging condition of the hoisted load-piece.  
25 As a result, it is possible to simplify the determination of

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the operating condition and its operating control. Further, it is possible to establish proper control of driving the transverse trolley and sheave blocks in order to effect optimal sway-damping.

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## 6. CLAIMS

(1) A swaying hoisted load-piece damping control apparatus for use in a load-piece hoisting device having a transverse trolley for hoisting a load-piece, and a pair of, or right and left, sheave blocks which are disposed along moving directions of said transverse trolley in parallel with the sides of said transverse trolley and movable relative to said transverse trolley, comprising:

trolley moving condition quantity detectors for detecting moving condition quantities of said transverse trolley;

hoisted load-piece moving condition quantity detectors for detecting moving condition quantities on right and left sides of the load-piece hoisted by said transverse trolley;

sheave-block moving condition quantity detectors for detecting moving condition quantities of said right and left sheave blocks;

a notch-driving control quantity detector for detecting transverse notch-driving control quantity of said trolley controlled by means of an operation controlling panel; and

a controller for effecting sway-damping control of said load-piece hoisting device based on detection signals obtained from said detectors,

characterized in that said controller has an optimizing control unit which sets up optimal controlling quantities for





the hoisted load-piece in accordance with moving condition quantities and notch-driving control quantity detected from said detectors, on the basis of a preset optimal gain for sway damping, and performs sway-damping control by driving said transverse trolley and said sheave blocks in accordance with the setup optimal controlling quantities.

2. A swaying hoisted load-piece damping control apparatus according to Claim 1 wherein said controller comprises: an operating condition determining unit which detects the operating condition of said transverse trolley, based on detected signals of the operating condition quantities and the notch-driving control quantity for said transverse trolley; an operating-condition-classifying optimal-gain selecting unit which, in accordance with the operating condition detected by said operating condition determining unit, selects an operating-condition-classifying optimal gain for sway damping from a plurality of predetermined optimal gains; and an optimizing control unit which, based on the optimal gain outputted from said operating-condition-classifying optimal-gain selecting unit, sets up optimal controlling quantities for the hoisted load-piece and performs sway-damping control by driving said transverse trolley and said sheave blocks in accordance with the setup optimal controlling quantities.

3. A swaying hoisted load-piece damping control apparatus





according to Claim 1 wherein said controller comprises: an independently controlling optimal-gain calculating unit which calculates independent optimal gains used to control transverse sway and skew sway of the hoisted load-piece, independently one from the other and outputs the calculated optimal gains; and an optimizing control unit for effecting sway-damping control which, based on the optimal gains outputted from said independently controlling optimal-gain calculating unit, sets up optimal controlling quantities for hoisted load-piece and performs sway-damping control by driving said transverse trolley to damp transverse sway of the load-piece and driving said right and left sheave blocks to damp skew sway of the load-piece.

4. A swaying hoisted load-piece damping control apparatus according to Claim 1 wherein said controller comprises: an independently controlling optimal-gain calculating unit which calculates independent optimal gains used to control transverse sway and skew sway of the hoisted load-piece, independently one from the other and outputs the calculated optimal gains; an operating condition determining unit which detects the operating condition of said transverse trolley, based on detected signals of the operating condition quantities and the notch-driving control quantity for said transverse trolley; an operating-condition-classifying optimal-gain selecting unit which, in accordance with the

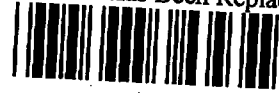


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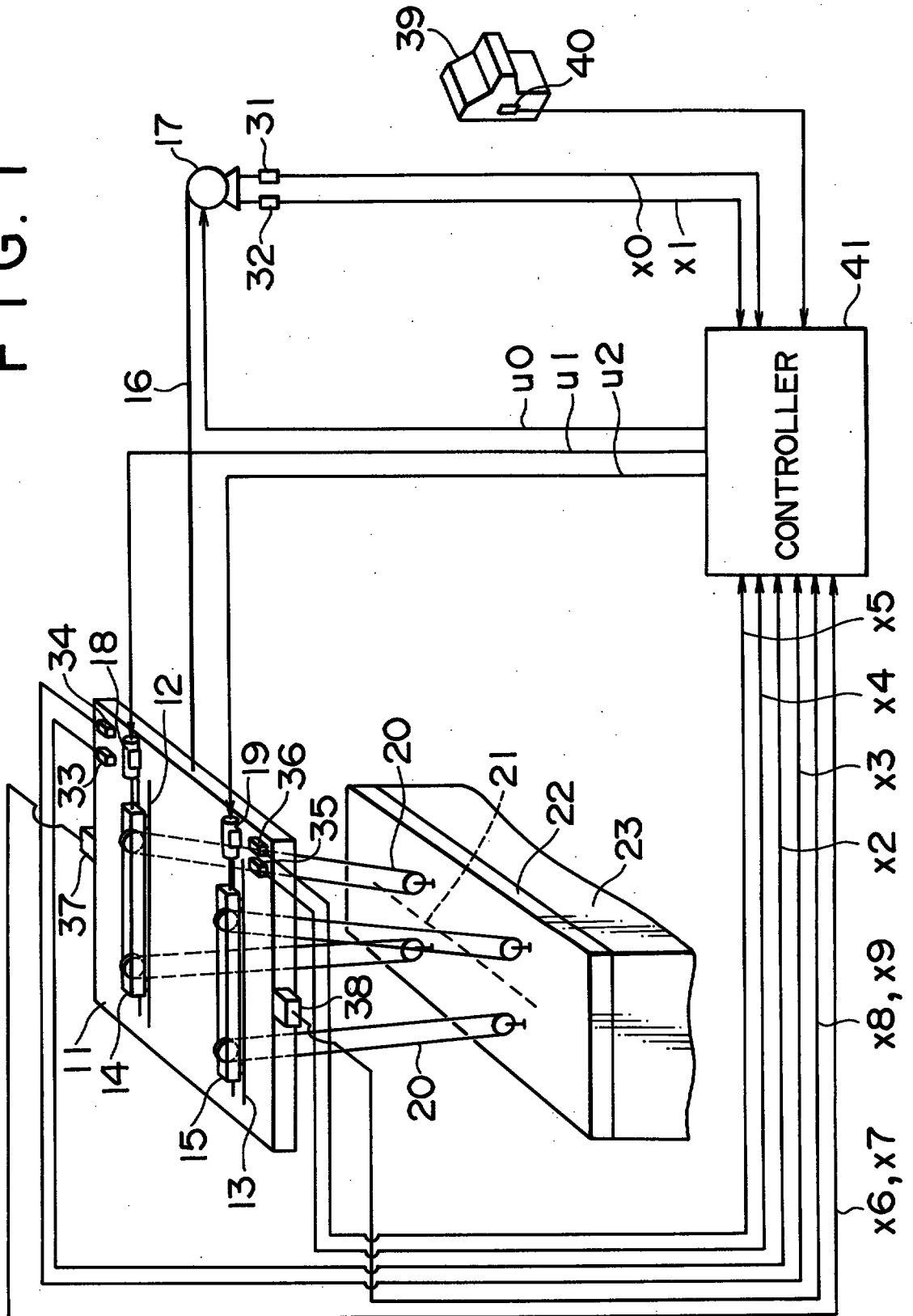
operating condition detected by said operating condition determining unit, selects a preset operating-condition-classifying optimal gain or an operating-condition-classifying optimal gain set up by said independently controlling optimal-gain calculating unit and outputs the selected gain; and an optimizing control unit which, based on the optimal gain outputted from said operating-condition-classifying optimal-gain selecting unit, sets up optimal controlling quantities for the hoisted load-piece and performs sway-damping control by driving said transverse trolley and said sheave in accordance with the setup optimal controlling quantities.

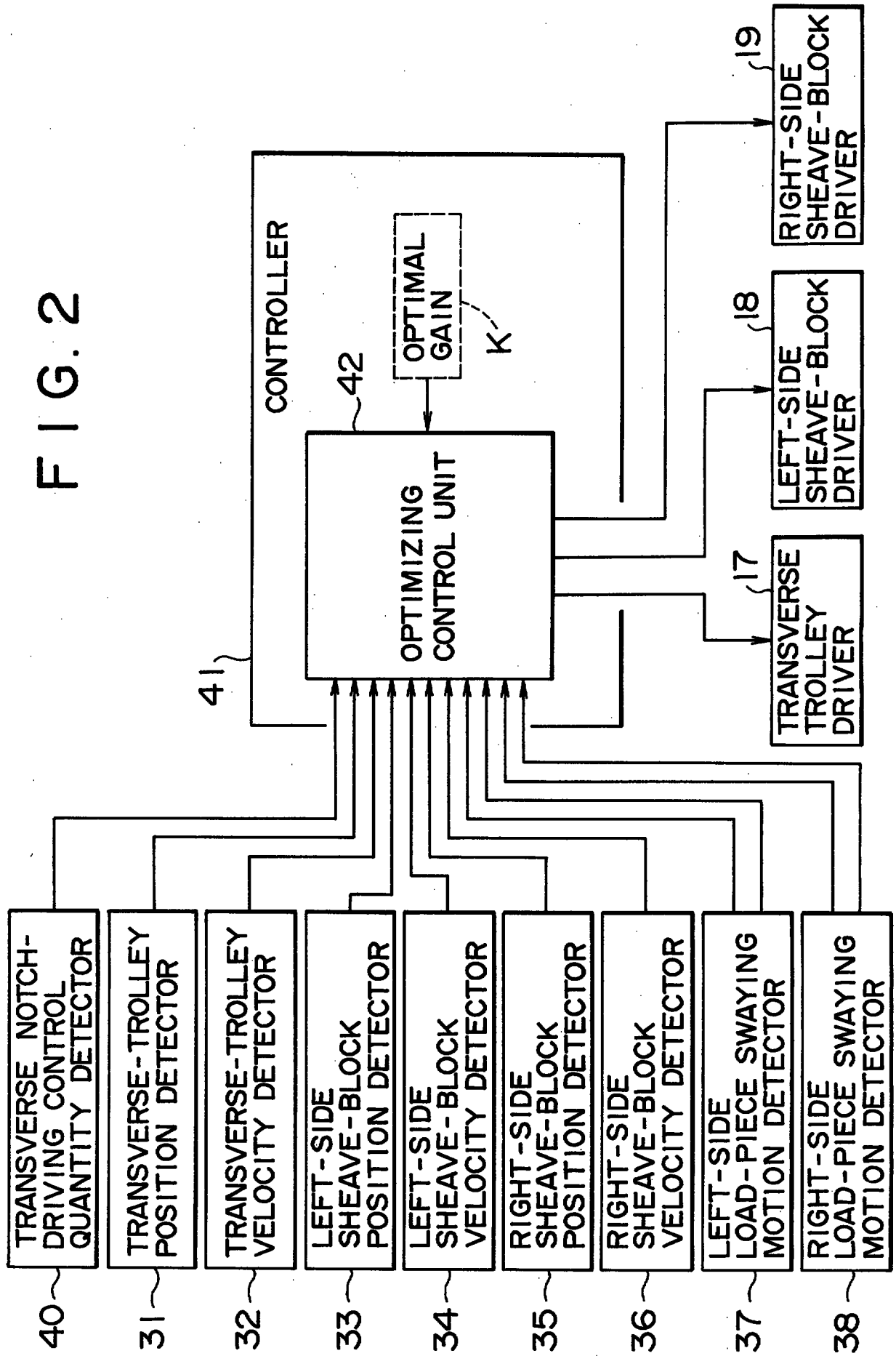




## 7. ABSTRACT

A pair of sheave blocks 14, 15 which is movable relative to a transverse trolley 11 are disposed on both (right and left) sides of a transverse trolley 11. Detectors 31 through 38 are provided which detect the moving condition quantity of the transverse trolley 11, the moving condition quantities of a hoisted load-piece 23 on both (right and left) sides and the moving condition quantities of the two sheave blocks 14, 15 while a transverse notch-driving control quantity detector 40 is provided on an operation control panel 39 for the transverse trolley 11. A controller is provided which effects sway-damping control of the load-piece hoisting device based on detection signals obtained from the detectors 31 through 38 and 40, and an optimizing control unit performs sway-damping control with optimal controlling quantities on the basis of a preset optimal gain  $K$  in accordance with the moving condition quantities and the notch-driving control quantity.





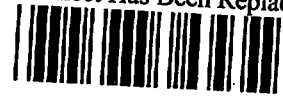
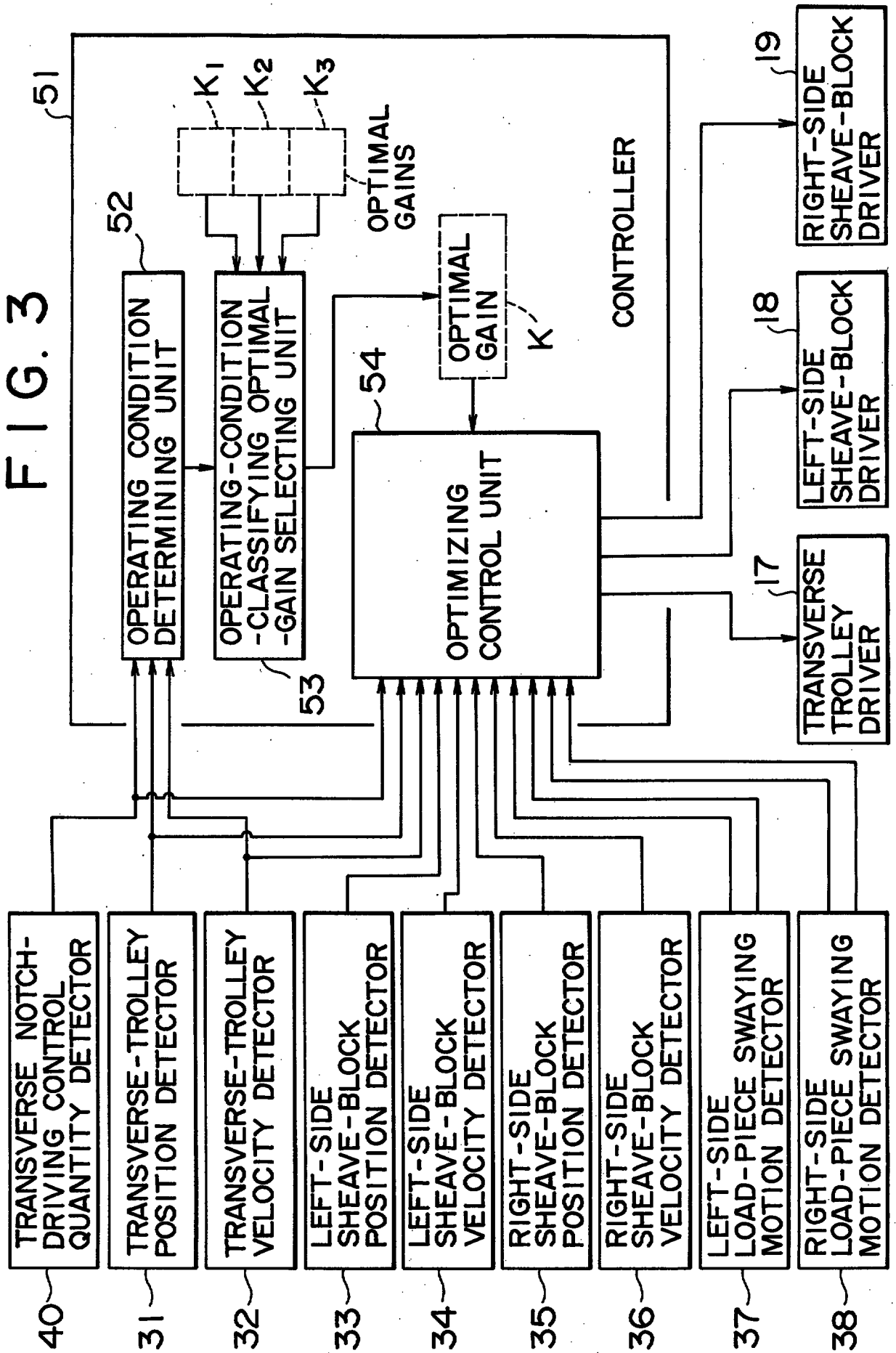


FIG. 3



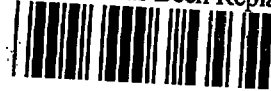


FIG. 4

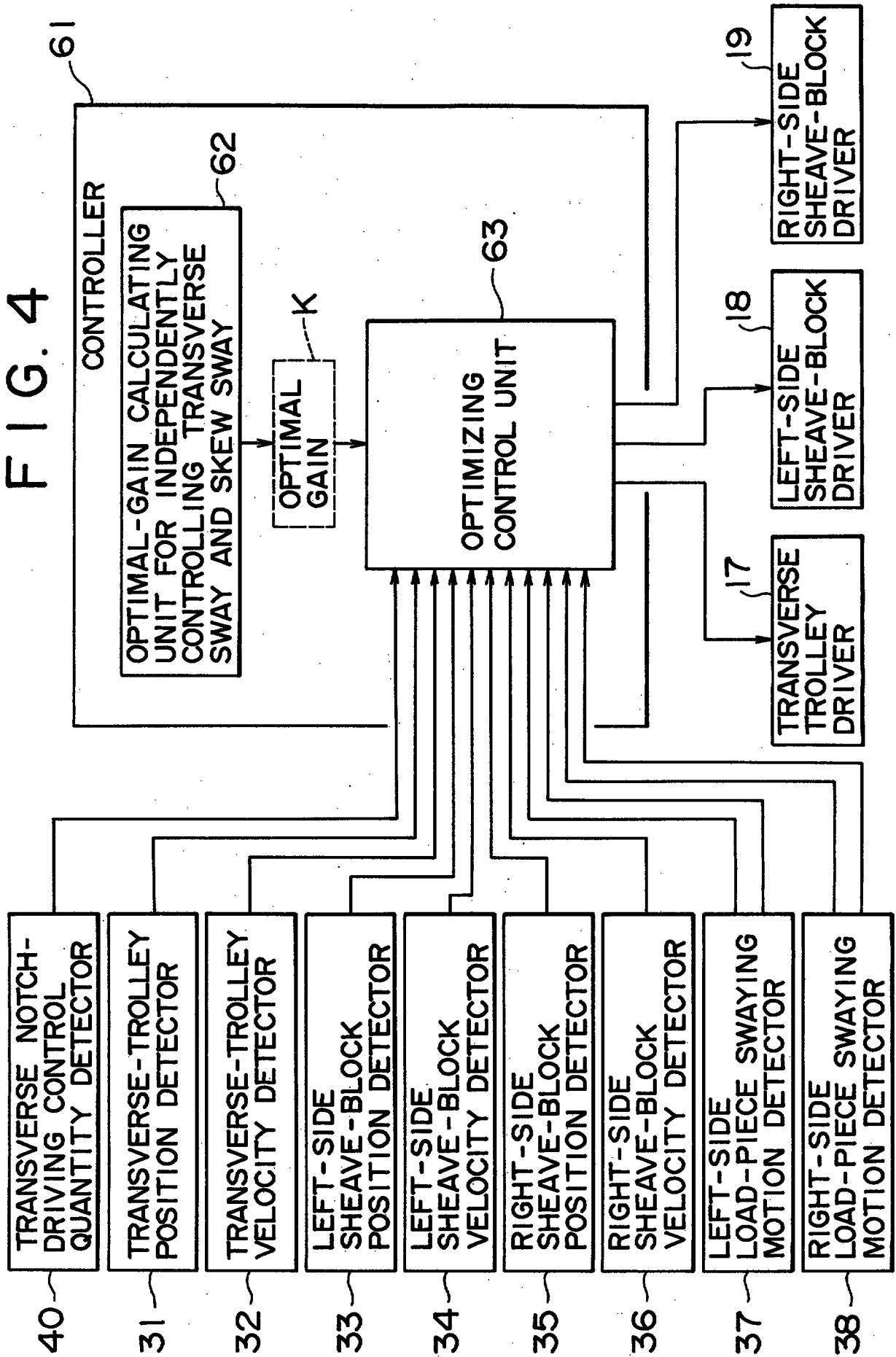




FIG. 5

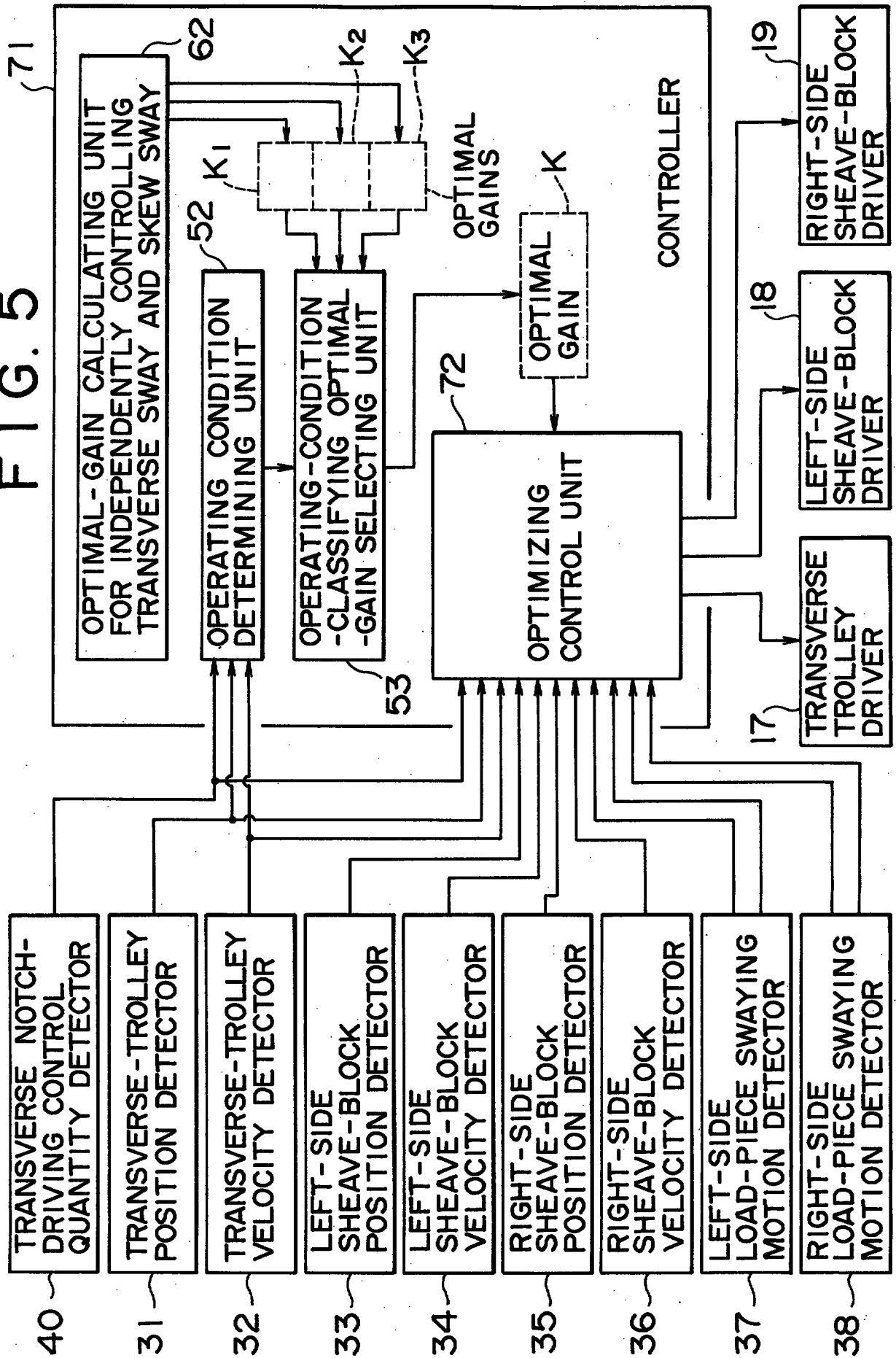






FIG. 7a

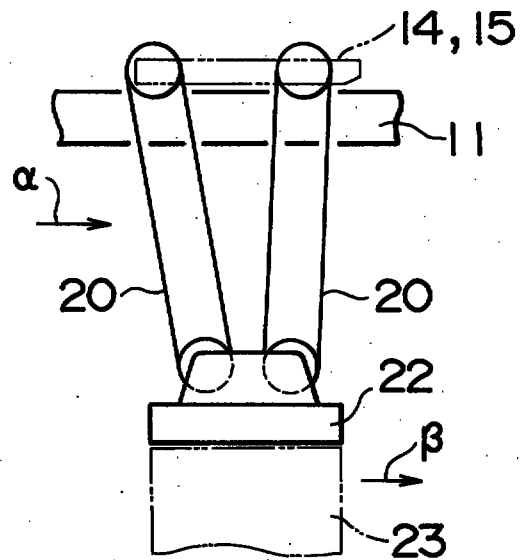
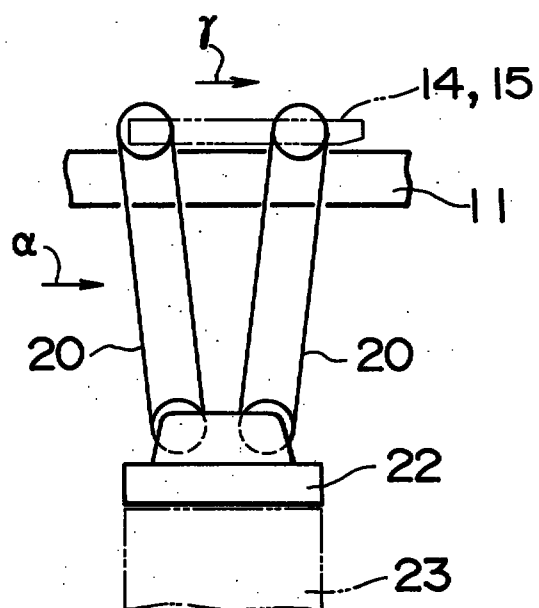
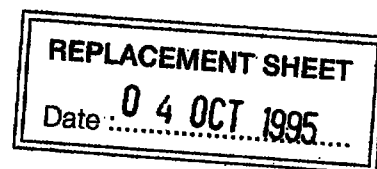


FIG. 7b





## SPECIFICATION

## 1. TITLE OF THE INVENTION

A SWAYING HOISTED LOAD-PIECE DAMPING CONTROL APPARATUS

## 2. FIELD OF THE INVENTION AND RELATED ART STATEMENT

## 5 (1) Field of the Invention

The present invention relates to a swaying hoisted load-piece damping control apparatus, and more detailedly relates to a swaying hoisted load-piece damping control apparatus for a load-piece hoisting device used in a large-scale load-piece lifting container crane and the like.

## 10 (2) Description of the Prior Art

Fig.6 shows an overall configuration of a swaying hoisted load-piece damping apparatus for used in a conventional container crane and Fig.7 shows operating states of the conventional swaying hoisted load-piece damping apparatus.

As shown in Fig.6, a transverse trolley 11 is provided transversally movable (movable in the side-to-side directions in Fig.6) on an unillustrated main crane girder. The transverse trolley 11 has a pair of rails 12 and 13 thereon which guide a pair of sheave blocks 14 and 15, respectively so that the sheave blocks 14 and 15 can move within short range in parallel with the moving direction of the transverse trolley 11. The transverse trolley 11 is connected through a wire 16 to a trolley driver 17 disposed on the main girder

(not shown) on which the transverse trolley 11 moves. The sheave blocks 14 and 15 have respective sheave block drivers 18 and 19 for driving the sheave blocks 14 and 15. A hoisting attachment 22 is hanged from the transverse trolley 11 through winding wires 20. This hoisting attachment 22 hoists a container 23 as a hoisted load-piece. Here, as shown in Fig.6, the hoisting attachment 22 has a detecting mark 21 for detecting the sway of the hoisted load-piece.

In stopping the sway of such a load-piece hoisting device, the operator in the operator cab, visually observing the motion of the hoisting attachment 2, used to perform manual remote-control operations in the following manner.

That is, in the state shown in Fig.6, when the trolley drivers 17 drives the transverse trolley 11 from the left to the right in a direction shown by an arrow  $\alpha$ , if the movement of the transverse trolley 11 is changed from the constant-speed transverse travel mode to the retarding travel mode, the hoisted load-piece 23 hanged by the hoisting attachment 22 sways rightward (forward) due to its inertia, as indicated by an arrow  $\beta$  in Fig.7(a). As the operator in the operator cab watches the detecting mark 21 on the hoisting attachment 22 and perceives the sway, the operator controls the transverse trolley 11 to accelerate as indicated by an arrow  $\gamma$  in Fig.7(b), in conformity with the transverse sway of the hoisted load-piece 23 (in the aforementioned direction of the

arrow  $\beta$ ). Alternatively, the two sheave blocks 14, 15 may be controlled to move in the same direction with the swaying direction of the hoisted load-piece 23 by activating the sheave block drivers 18, 19. Thereafter, the operator tries to control the transverse trolley 11 to retard in time with the reverse motion of the hoisted load-piece 23 after the trolley completes a forward-swing of a certain magnitude or should control the sheave blocks 14, 15 to move in the opposite direction to the aforementioned direction so that the transversally swinging load-piece is dampened to stop.

In the case shown in Fig.6, if, for example, the hoisted load-piece 23 sways clockwise causing skew sway on a plane as indicated by arrows A, the operator again perceives it from the movement of the detecting mark 21 and activates the driver 18, 19 so as to move the sheave block 15 leftward (in the direction shown by an arrow B) and the other sheave block 14 rightward (in the direction shown by an arrow C) in synchronism with the skew sway. To deal with a repulsive swing of the hoisted load-piece 23, the sheave blocks 14, 15 may and should be driven in the opposite directions to those described above, so that the skew sway is attenuated to stop.

The conventional, swaying hoisted load-piece damping apparatus in which sway is manually stopped by the operator, however, suffers from problems as follows:

That is, as stated above, it is true that simple

transverse sway or simple skew sway of the hoisted load-piece 23 can be attenuated and stopped by the operator by accelerating and/or retarding the transverse trolley 11 or by moving the sheave blocks 14,15 in synchronism with the swinging state of the hoisting attachment 22. But, if transverse sway and skew sway occur at the same time and cause the hoisted load-piece 23 to make a complex motion, it becomes difficult or practically impossible for the operator to manually drive the transverse trolley 11 or the sheave blocks 14, 15 well enough to deal with the situation.

As soon as the hoisted load-piece 23 is stopped to sway, the sheave blocks must normally be returned by force to their home positions or the middle of the transverse trolley 11 with respect to the transverse direction, so that the two (left and right) sheaves 14 and 15 can move in either transverse direction to prepare for a next swing of the hoisted load-piece 23. In order to improve the efficiency of conveying the hoisted load-piece 23, the transverse trolley 11 must be driven at a maximum speed during it travels transversally. When the hoisted load-piece 23 comes near a target position where it is to be unloaded onto the ground, the transverse trolley 11 should be retarded so as to stop at the target position and then need be stopped at the target position where the load-piece is unloaded. To sum up, it is necessary to effect, all at once, position or control of the

sheave blocks 14 and 15, velocity and/or position control of the transverse trolley 11 in conformity with the transverse position and conditions, other than the control of damping the swaying hoisted load-piece 23. Nevertheless, since the conventional sway-damping operation is manually effected by the operator, the controlling operation requires the toughest techniques for even the skilled operators.

### 3. OBJECT AND SUMMARY OF THE INVENTION

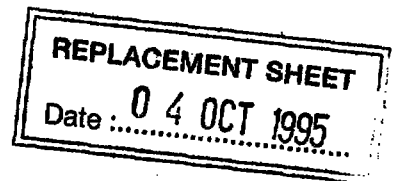
The present invention has been achieved to solve the above problems and it is therefore an object of the present invention to provide a swaying hoisted load-piece damping control apparatus which simplifies the operation of damping swaying hoisted load-piece and is able to achieve the damping operation in an assured manner.

Another object of the present invention is to provide a swaying hoisted load-piece damping control apparatus which is able to realize an optimal control for damping and stopping a swaying hoisted load-piece as fast as possible by automating the complicated swaying hoisted load-piece damping operation.

A further object of the present invention is to provide a swaying hoisted load-piece damping control apparatus which is able to improve the work efficiency of conveying hoisted load-pieces by markedly reducing the work amount of the operator and the time required for sway damping.

Date: 04 OCT 1995

In order to attain the above objects, a swaying hoisted load-piece damping control apparatus (an apparatus defined in Claim 1) for use in a load-piece hoisting device having a transverse trolley for hoisting a load-piece, and a pair of, or right and left, sheave blocks which are disposed along moving directions of the transverse trolley in parallel with the sides of the transverse trolley and movable relative to the transverse trolley, comprises: trolley moving condition quantity detectors for detecting moving condition quantities of the transverse trolley; hoisted load-piece moving condition quantity detectors for detecting moving condition quantities on right and left sides of the load-piece hoisted by the transverse trolley; sheave-block moving condition quantity detectors for detecting moving condition quantities of the right and left sheave blocks; a notch-driving control quantity detector for detecting transverse notch-driving control quantity of the trolley controlled by means of an operation controlling panel; and a controller for effecting sway-damping control of the load-piece hoisting device based on detection signals obtained from the detectors, and constructed such that the controller has an optimizing control unit which sets up optional controlling quantities for the hoisted load-piece in accordance with moving condition quantities and notch-driving control quantity detected from said detectors, on the basis of a preset



optimal gain for sway damping, and performs sway-damping control by driving said transverse trolley and said sheave blocks in accordance with the setup optimal controlling quantities.

5           According to the present invention, in the swaying hoisted load-piece damping control apparatus defined in Claim 1, the controller comprises: an operating condition determining unit which detects the operating condition of the transverse trolley, based on detected signals of the  
10   operating condition quantities and the notch-driving control quantity for the transverse trolley; an operating-condition-classifying optimal-gain selecting unit which, in accordance with the operating condition detected by the operating condition determining unit, selects an operating-condition-  
15   classifying optimal gain for sway damping from a plurality of predetermined optimal gains; and an optimizing control unit which, based on the optimal gain outputted from the operating-condition-classifying optimal-gain selecting unit, sets up optimal controlling quantities for the hoisted load-  
20   piece and performs sway-damping control by driving the transverse trolley and the sheave blocks in accordance with the setup optimal controlling quantities.

          According to the present invention, in the swaying hoisted load-piece damping control apparatus defined in Claim  
25   1, the controller comprises: an independently controlling

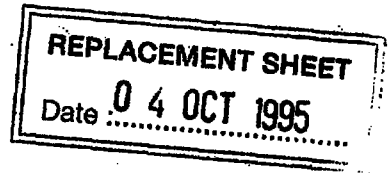


optimal-gain calculating unit which calculates independent optimal gains used to control transverse sway and skew sway of the hoisted load-piece, independently one from the other and outputs the calculated optimal gains; and an optimizing control unit for effecting sway-damping control which, based on the optimal gains outputted from the independently controlling optimal-gain calculating unit, sets up optimal controlling quantities for hoisted load-piece and performs sway-damping control by driving the transverse trolley to damp transverse sway of the load-piece and driving the right and left sheave blocks to damp skew sway of the load-piece.

According to the present invention, in the swaying hoisted load-piece damping control apparatus defined in Claim 1, the controller comprises: an independently controlling optimal-gain calculating unit which calculates independent optimal gains used to control transverse sway and skew sway of the hoisted load-piece, independently one from the other and outputs the calculated optimal gains; an operating condition determining unit which detects the operating condition of the transverse trolley, based on detected signals of the operating condition quantities and the notch-driving control quantity for the transverse trolley; an operating-condition-classifying optimal-gain selecting unit which, in accordance with the operating condition detected by the operating condition determining unit, selects a preset

operating-condition-classifying optimal gain or an operating-condition-classifying optimal gain set up by the independently controlling optimal-gain calculating unit and outputs the selected gain; and an optimizing control unit which, based on the optimal gain outputted from the operating-condition-classifying optimal-gain selecting unit, sets up optimal controlling quantities for the hoisted load-piece and performs sway-damping control by driving the transverse trolley and the sheave blocks in accordance with the setup optimal controlling quantities.

In accordance with the swaying hoisted load-piece damping control apparatus of the present invention, as the container crane is activated, detection signals as to moving condition quantities are detected by the transverse trolley moving condition quantity detector, the right- and left-sheave-block operating condition quantity detectors and the hoisted load-piece moving condition quantity detectors for detecting the movement on right and left sides of the load-piece while the operating quantity signal is detected by the notch-driving control quantity detector. The thus detected signals are sent to the controller. In the controller, an optimal gain for sway damping is previously determined in conformity with the moving condition quantities of the hoisted load-piece such as transverse sway and skew sway during the transverse trolley travels transversally, at the



time of retardation for positioning, or in the stopping state, and then the optimizing control unit effects sway-damping control by driving the transverse trolley and the sheave blocks by optimal controlling quantities set up in accordance with operating condition quantities of the hoisted load-piece on the basis of the optimal gain.

The operating condition determining unit, based on the signals from the transverse trolley moving condition detectors and from the notch-driving control quantity detector, determines which condition the transverse trolley is in, specifically, the condition in which the transverse trolley travels, the condition in which the trolley is retarded for positioning or the condition in which the trolley is stopped with the hoisted load-piece swaying alone. The determined signal is outputted to the operating-condition-classifying optimal gain selecting unit. This operating-condition-classifying optimal gain selecting unit, as receiving the determine signal, selects any one of optimal gains previously set up according to plural classifying operating conditions and outputs the thus selected optimal gain to the optimizing control unit. The optimizing control unit sets up an optimal controlling quantity in accordance with the moving condition quantity of the hoisted load-piece on the basis of the selected optimal gain and drives the transverse trolley and the sheave blocks by the thus set up

by optimal controlling quantities, to thereby perform sway-damping control.

The independently controlling optimal gain calculating unit calculates a required optimal gain for damping transverse sway and skew sway of the hoisted load-piece so as to output it to the optimizing control unit. The optimizing control unit effects sway-damping control by driving the transverse trolley based on the optimal gain component for damping transverse sway and driving the right and left sheave blocks based on the optimal gain component for damping skew sway.

The independently controlling optimal gain calculating unit calculates a required optimal gain for damping transverse sway and skew sway of the hoisted load-piece so as to output it to the operating-condition-classifying optimal gain selecting unit while the operating condition determining unit, based on the signals from the transverse trolley operating condition detectors and from the notch-driving control quantity detector, determines which condition the transverse trolley is in, specifically, the condition in which the transverse trolley travels, the condition in which the trolley is retarded for positioning or the condition in which the trolley is stopped with the hoisted load-piece swaying alone and outputs the determined signal to the operating-condition-classifying optimal gain selecting unit.

The operating-condition-classifying optimal gain selecting unit, as receiving these determined signals, selects one of the optical gains classified according to the operating condition and outputs it as an optical gain to the optimizing control unit. The optimizing control unit effects sway-damping control by driving the transverse trolley based on the optimal gain component for damping transverse sway and driving the right and left sheave blocks based on the optimal gain component for damping skew sway.

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#### 4. BRIEF DESCRIPTION OF THE DRAWINGS

Fig.1 is a schematic constructional view showing an overall configuration of a swaying hoisted load-piece damping control apparatus in accordance with an embodiment of the present invention;

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Fig.2 is a block diagram showing a first embodiment of a controlling apparatus;

Fig.3 is a block diagram showing a second embodiment of a controlling apparatus;

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Fig.4 is a block diagram showing a third embodiment of a controlling apparatus;

Fig.5 is a block diagram showing a fourth embodiment of a controlling apparatus;

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Fig.6 is a schematic view showing a conventional swaying hoisted load-piece damping apparatus for use in a



prior art container crane; and

Fig.7 shows illustrations of operating conditions of the conventional swaying hoisted load-piece damping apparatus.

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#### 5. DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Embodiments of the present invention will hereinafter be described in detail with reference to Figs.1 through 5.

Fig.1 schematically shows an overall configuration of a swaying hoisted load-piece damping control apparatus in accordance with an embodiment of the present invention. Fig.2 is a controlling block for explaining a first embodiment of a controlling apparatus. In Fig.1, identical reference numerals are allotted to components having the same functions with those in the prior art shown in Fig.6 and repeated description for those is omitted.

As shown in Fig.1, in a controlling apparatus for damping a swaying hoisted load-piece of this embodiment, the trolley driver 17 of the transverse trolley 11 includes a position or displacement detector 31 and a velocity detector 32 as detectors for detecting trolley operating condition quantities. The left-side sheave block 14 is provided with a position or displacement detector 33 and a velocity detector 34 as detectors for detecting moving condition quantities of the sheave block. In the same manner, the right-side sheave



block 15 is provided with a position or displacement detector 35 and a velocity detector 36. In order to detect moving condition quantities of the hoisted load-piece, swaying motion detectors 37, 38 are provided respectively on left and right sides of the transverse trolley 11 so as to check the motion of the detecting mark 22 on the hoisting attachment 22 and thereby detect left-side and right-side swaying positions or displacements and velocities of the hoisted load-piece 23. Further, a transverse operation controlling panel 39 in the crane operator cab is equipped with a transverse notch-driving control quantity detector 40.

A controller 41 is to receive detection signals from all the moving condition quantity detectors 31 through 38 and the transverse notch-driving control quantity detector 40 (see Figs.1 and 2), to calculate optimal controlling quantities required for neutralizing the operating condition quantities inputted, or nullifying the swinging momentum of the hoisted load-piece 23, and to output control command signals to the driver 17 for the transverse trolley 11 and drivers 18, 19 for left and right sheave blocks 14, 15.

The controller 41, as shown in Fig.2, has an optimizing control unit 42 which, based on an optimal gain  $K$  for sway damping which is previously calculated and set up separately in the controller 41, determines optimal controlling quantities in accordance with the moving condition quantities



of the hoisted load-piece 23 and the operating condition quantities of the transverse trolley 11 supplied from detectors 31 through 38 and 40 and thereby controls the driver 17 of the transverse trolley 11 and drivers 18, 19 for  
5 respective (left and right) sheave blocks 14, 15 so that optimal damping can be done.

Now, description will be made on a specific operational process of sway damping using the swaying hoisted load-piece damping control apparatus of the embodiment described above.

10 (1) First of all, detectors 31 through 38 and 40 detect moving condition quantities of the transverse trolley 11, the sheave blocks 14, 15 and the hoisted load-piece 23 and a transverse notch-driving control quantity and output the detected signals to the controller 41.

15 (2) Next, these moving condition quantities and transverse notch-driving control quantity are used in the optimizing control unit 42 for calculation of optimal sway-damping control to calculate a velocity command  $u_0$  for the transverse trolley 11 and velocity commands  $u_1$ ,  $u_2$  for the sheave blocks  
20 14, 15 by the following formula [1]:

$$u = K \times x \dots [1]$$

Here, 'u' represents a controlling (operating) quantity vector shown as follows and the elements are the velocity command  $u_0$  for the transverse trolley 11, the velocity  
25 command  $u_1$  for the left-side sheave block 14 and the velocity

command u2 for the right-side sheave block 15, in order from the left, and more explicitly, 'u' can be defined as the following equation [2]:

$$u = \begin{pmatrix} u0 \\ u1 \\ u2 \end{pmatrix} \dots [2]$$

A condition quantity vector 'x' is defined as follows. That is, the elements are, in the descending order, a position or displacement x0 and a velocity x1 of the transverse trolley 11, a position or displacement x2 and a velocity x3 of the left sheave block 14, a position or displacement x4 and a velocity x5 of the right sheave block 15, a position or displacement x6 and a velocity x7 of the hoisted load-piece 23 on its left side, and a position or displacement x8 and a velocity x9 of the hoisted load-piece 23 on its right side. Explicitly, 'x' can be expressed as the following equation [3]:

$$x = \begin{pmatrix} x0 \\ x1 \\ x2 \\ x3 \\ x4 \\ x5 \\ x6 \\ x7 \\ x8 \\ x9 \end{pmatrix} \dots [3]$$

A  $3 \times 10$  constant matrix 'K' defined by the following equation [4] represents an optimal gain matrix:

$$K = \begin{bmatrix} k_{00} & k_{01} & k_{02} & k_{03} & k_{04} & k_{05} & k_{06} & k_{07} & k_{08} & k_{09} \\ k_{10} & k_{11} & k_{12} & k_{13} & k_{14} & k_{15} & k_{16} & k_{17} & k_{18} & k_{19} \\ k_{20} & k_{21} & k_{22} & k_{23} & k_{24} & k_{25} & k_{26} & k_{27} & k_{28} & k_{29} \end{bmatrix} \dots [4]$$

Here, the constant matrix K as an optimal gain is to be calculated previously by the following procedures.

1) From the equations of motion for the transverse trolley 11, the two (left and right) sheave blocks 14, 15 and swinging motions on the right and left sides of the hoisted load-piece 23, the following equation of state shown by [5] is derived. This state equation is a liner differential equation which represents the swing of the hoisted load-piece 23 by a spring-mass system of transverse and skew movement. Here, detailed description of the state equation, inclusive of its derivation, is omitted.

$$\dot{x} = A \times x + B \times u \dots [5]$$

where u and x represent the aforementioned controlling quantity vector and condition quantity vector, respectively, while A designates a  $10 \times 10$  constant matrix and B designates a  $10 \times 3$  constant matrix.

2) For the above state equation [5], an optimal gain K defined as in the following equation [7] is determined so that an evaluation function J defined by the following

equation [6] takes a minimum value.

$$J = \int_0^{\infty} (x^T \times Q \times x + u^T \times R \times u) dt \quad \dots[6]$$

$$u = K \times x \quad \dots[7]$$

where Q and R represent weighing matrices of 10 x 10 and 3 x 3, respectively.

In this way, by minimizing the evaluation function J, the optimal gain K is to be determined to neutralize or nullify all the elements of the condition quantity x' as fast as possible using the smallest controlling quantity 'u'.

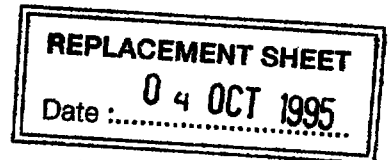
(3) Based on the optimal gain K determined by the above calculation, the optimizing control unit 42 calculates optimal controlling quantities in conformity with the moving condition quantities and the operating condition detected by the detectors 31 through 38 and 40. The thus obtained optimal controlling quantities are outputted to the drivers 17, 18 and 19 for the transverse trolley 11, the two (left and right) sheave blocks 14 and 15, as control command signals for velocity commands u0, u1 and u2; whereby the optimal control for sway damping of the hoisted load-piece is effected.

Fig.3 shows a controlling block representing a second embodiment of a swaying hoisted load-piece damping control



apparatus of the present invention.

As shown in Fig.3, in this embodiment, a controller 51 is composed of: an operating condition determining unit 52 which, receiving detected signals from a transverse notch-driving control quantity detector 40, position and velocity  
5 detectors 31 and 32 of a transverse trolley driver 17, determines the operating condition of a transverse trolley 11 or which condition the transverse trolley 11 is in, specifically, a condition in which the trolley 11 is driven, a condition in which the trolley 11 is in the middle of  
10 retardation to stop at a target place or a condition in which the trolley 11 need sway damping after the positioning, to thereby deliver output signals; an operating-condition-classifying optimal-gain selecting unit 53 which, based on  
15 the signals from the operating condition determining unit 52 and a plurality of operating-condition-classifying optimal gains  $K_1$ ,  $K_2$  and  $K_3$  which are previously calculated and set up for the different operating conditions, selects an optimal gain  $K$  for the detected operating condition from the  
20 operating-condition-classifying optimal gains  $K_1$ ,  $K_2$  and  $K_3$ ; and an optimizing control unit 54 which, receiving the optimal gain  $K$  selected in the operating-condition-classifying optimal-gain selecting unit 53, sets up optimal  
25 controlling quantities in accordance with moving condition quantities inputted from the detectors 31 through 38 and



effects optimal control for sway damping by the drivers 17 of the transverse trolley 11, the drivers 18, 19 of respective (left and right) sheave blocks 14, 15.

Now, description will be made on a specific sway-damping process effected by the controller 51 of this embodiment.

(1) The operating condition determining unit 52 determines the operating condition of the transverse trolley 11 based on the detected signals from the transverse notch-driving control quantity detector 40, the position and velocity detectors 31, 32 of the transverse trolley driver 17. At that moment, if the operator is performing a notch-driving operation or the notch-driving operation quantity is not zero, the unit 52 judges that the hoisted load-piece 23 is still far from a target position where the load-piece is to be placed on the ground. When the notch-driving operation quantity becomes equal to zero, the unit 52 judges that the load-piece comes near the target position. When the notch-driving operation quantity is equal to zero and the transverse trolley position information indicates that the load-piece 23 is at the target position with the transverse velocity equal to zero, the hoisted load-piece 23 is judged as to reach the target position.

(2) The operating-condition-classifying optimal-gain selecting unit 53 selects as the optimal gain  $K$  any one of

three optimal gains  $K_1$ ,  $K_2$  and  $K_3$  in accordance with the operating condition determined in (1). Here, the optimal gains  $K_1$ ,  $K_2$  and  $K_3$  are determined in the same manner as described in the procedures 1) and 2) of (2) of the first embodiment, using the following three evaluation functions  $J_1$ ,  $J_2$  and  $J_3$  shown in [8] for the optimal gains  $K_1$ ,  $K_2$  and  $K_3$ , respectively.

$$\left. \begin{aligned} J_1 &= \int_0^{\infty} (\dot{x}^T \times Q_1 \times \dot{x} + u^T \times R \times u) dt \\ J_2 &= \int_0^{\infty} (x^T \times Q_2 \times x + u^T \times R \times u) dt \\ J_3 &= \int_0^{\infty} (x^T \times Q_3 \times x + u^T \times R \times u) dt \end{aligned} \right\} \dots [8]$$

Accordingly, the thus obtained three kinds of optimal gains are classified as  $K_1$ ,  $K_2$  and  $K_3$  in correspondence with  $J_1$ ,  $J_2$  and  $J_3$ , respectively.

Here,  $Q_1$  is a weighing matrix for a velocity following type optimal-gain calculation mode in which the operator effects notch-driving operation in accordance with the velocity of the transverse trolley 11 without effecting positional control of the transverse trolley 11,  $Q_2$  is a weighing matrix for a positional control type optimal-gain calculation mode in which the transverse trolley 11 is controlled so as to reach the target position, and  $Q_3$  is a

weighing matrix for a sway-damping type optimal-gain  
 ,calculation mode in which the transverse trolley 11 is  
 positioned and sway damping is effected by the sheave blocks  
 14 and 15 alone. R is a constant matrix and may be a unit  
 5 matrix, for instance.

The weighing matrices  $Q_1$ ,  $Q_2$  and  $Q_3$  are represented by  
 the following matrices [9]:

$$Q_1 = \begin{pmatrix} 0 & & & & & & & & & \\ & q_1 & & & & & & & & \\ & & q_2 & & & & & & & \\ & & & q_3 & & & & & & \\ & & & & q_4 & & & & & \\ & & & & & q_5 & & & & \\ & & & & & & q_6 & & & \\ & & 0 & & & & & q_7 & & \\ & & & & & & & & q_8 & \\ & & & & & & & & & q_9 \end{pmatrix}$$

$$Q_2 = \begin{pmatrix} q_0 & & & & & & & & & \\ & q_1 & & & & & & & & \\ & & q_2 & & & & & & & \\ & & & q_3 & & & & & & \\ & & & & q_4 & & & & & \\ & & & & & q_5 & & & & \\ & & & & & & q_6 & & & \\ & & 0 & & & & & q_7 & & \\ & & & & & & & & q_8 & \\ & & & & & & & & & q_9 \end{pmatrix}$$

$$Q_3 = \begin{pmatrix} 0 & & & & & & & & \\ & 0 & & & & & & & \\ & & q_2 & & & & 0 & & \\ & & & q_3 & & & & & \\ & & & & q_4 & & & & \\ & & & & & q_5 & & & \\ & & & & & & q_6 & & \\ & 0 & & & & & & q_7 & \\ & & & & & & & & q_8 \\ & & & & & & & & & q_9 \end{pmatrix} \dots [9]$$

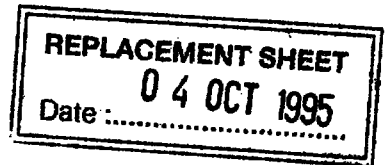
(3) The selection of an optimal gain K by the operating-condition-classifying optimal-gain selecting unit 53 is carried out as follows:

(a) If the load-piece stays far from the target place, the optimal gain  $K_1$  for the velocity following mode in which the operator effects notch-driving operation is selected as the optimal gain K.

(b) If the load-piece is brought close to the target place, the optimal gain  $K_2$  for the positional control mode in which the transverse trolley 11 is controlled so as to reach the target place is selected as the optimal gain K.

(c) If the load-piece is positioned at the target place, the optimal gain  $K_3$  for the sway-damping mode in which sway is damped by the sheave blocks 14 and 15 alone is selected as the optimal gain K.

(4) Then, in the same manner as in the first embodiment, the moving condition quantities and the transverse notch-driving control quantity detected by the detectors 31 through



38 and 40 are outputted to the controller 51.

(5) From the operating condition inputted, the controller 51 makes the optimizing control unit 54 effect the calculation of sway-damping optimizing control based on the  
5   aforementioned equation [1] to determine the velocity command  $u_0$  for the transverse trolley 11 and velocity commands  $u_1$  and  $u_2$  for respective sheave blocks 14 and 15.

(6) The optimizing control unit 54, based on the optimal gain  $K$ , calculates optimal controlling quantities in  
10   conformity with the moving condition quantities and the operating condition detected by the detectors 31 through 38 and 40 and outputs the obtained optimal controlling quantities as control command signals for velocity commands  $u_0$ ,  $u_1$  and  $u_2$  to the drivers 17, 18 and 19 for the transverse  
15   trolley 11 and the two (left and right) sheave blocks 14 and 15, whereby the hoisted load-piece 23 is optimally controlled to stop swinging.

Thus, in accordance with the controller 51 described in the second embodiment, it is possible to eliminate the  
20   difficulties in the operating-condition classifying determination and the operation control in the conventional configuration by determining the operating condition of the transverse trolley 11 by the operating condition determining unit 52, allowing the operating-condition-classifying  
25   optimal-gain selecting unit 53 to select an individual

optimal gain K for each mode selected from the velocity following mode, the target-position reaching mode and the sway-damping mode using the sheave blocks 14 and 15, in correspondence with the operation condition of the transverse trolley 11, and making the optimizing control unit 54 effect optimal control of damping sway based on the selected optimal gain K.

Fig.4 shows a control block representing a third embodiment of a swaying hoisted load-piece damping control apparatus of the present invention.

As shown in Fig.4, a controller 61 of the present invention is composed of an optimal-gain calculating unit 62 for independently controlling transverse sway and skew sway in order to calculate optimal gains which are used when the transverse sway and skew sway are damped independently each from the other and an optimizing control unit 63 for effecting sway-damping control based on the optimal gain K determined by the resulting calculation in the optimal-gain calculating unit 62 for independently controlling transverse sway and skew sway. When both transverse and skew sway are detected simultaneously through the aforementioned detectors 31 through 38 and 40, the optimizing control unit 63 is to set up, in accordance with the detection, separate optimal controlling quantities for the transverse trolley driver 17 for damping the transverse sway and for the two (left and

right) sheave block drivers 18 and 19 for damping the skew sway based on the optimal gain K determined by the optimal-gain calculating unit 62 for independently controlling transverse sway and skew sway and thereby effect the damping control separately.

Now, description will be made on a specific flow of sway damping by the controller 61 of this embodiment.

(1) The optimal-gain calculating unit 62 for independently controlling transverse sway and skew sway calculates an optimal gain in the following way:

1) In the state equation [5] shown above, if  $x$  is substituted by  $x = T \times x'$  to effect a mode transformation, then the following state equation [10] can be obtained. Here,  $x'$  and  $T$  indicate a new condition quantity vector and a mode transforming matrix, respectively.

$$\dot{x}' = A' \times x' + B' \times u \quad \dots[10]$$

$$\text{where } A' = T^{-1} \times A \times T \quad B' = T^{-1} \times B$$

$$x' = \begin{pmatrix} x_0 \\ x_1 \\ x_2' \\ x_3' \\ x_4' \\ x_5' \\ x_6' \\ x_7' \\ x_8' \\ x_9' \end{pmatrix}$$

$$T = \begin{pmatrix} 1 & & & & \\ & 1 & & & \\ & 10 & 10 & & 0 \\ & 01 & 01 & & \\ & 10 & -10 & & \\ & 01 & 0 & -1 & \\ & & 10 & 10 & \\ 0 & & 01 & 01 & \\ & & 10 & -10 & \\ & & 01 & 0 & -1 \end{pmatrix}$$

In one word, a new state equation is derived with respect to a new condition quantity vector  $x'$  whose elements are: in the descending order,  $x_0$  and  $x_1$ : position or displacement and velocity of the transverse trolley 11;  $x_2'$  and  $x_3'$ : transverse components of the position or displacement and velocity of the sheave blocks 14, 15;  $x_4'$  and  $x_5'$ : skew components of the position or displacement and velocity of the sheave blocks 14, 15;  $x_6'$  and  $x_7'$ : transverse components of the position or displacement and velocity of the hoisted load-piece 23; and  $x_8'$  and  $x_9'$ : skew components of the position or displacement and velocity of the hoisted load-piece 23.

2) For the above state equation [10], an optimal gain matrix  $K'$  defined as in the following equation [12] is determined so that an evaluation function  $J$  defined by the following equation [11] takes a minimum value.

$$J = \int_0^{\infty} (x'^T \times Q \times x' + u^T \times R \times u) dt \quad \dots[11]$$

5

$$u = K' \times x' \quad \dots[12]$$

10 where Q and R represent weighing matrices of 10 × 10 and 3 × 3, respectively. Explicitly, Q can be expressed as follows:

$$Q = \begin{pmatrix} q_0 & & & & & & & & & \\ & q_1 & & & & & & & & \\ & & q_2 & & & & & & & \\ & & & q_3 & & & & & & \\ & & & & q_4 & & & & & \\ & & & & & q_5 & & & & \\ & & & & & & q_6 & & & \\ & & & & & & & q_7 & & \\ & & & & & & & & q_8 & \\ & & & & & & & & & q_9 \end{pmatrix}$$

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In this way, by minimizing the evaluation function J, the gain optimal matrix K' is to be determined to neutralize or nullify all the elements of the condition quantity x' as fast as possible using the smallest controlling quantity.

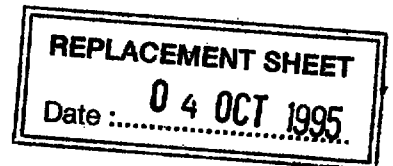
30 Here, the optimal allocation of tasks to the transverse trolley and the sheave blocks should be determined in order to achieve optimal control of sway damping. This depends on the setup of the weighing matrix Q appearing in the above equation [11].

35 Sway of the hoisted load-piece 23 during the transverse travel qualitatively comprises a large transverse swinging

motion, generated due to the inertial of the hoisted load-piece 23 when it is accelerated or retarded and a skew swinging motion relatively smaller than the transverse swinging motion, generated due to the eccentricity etc., of the hoisted load-piece 23. In order to damp the relative large transverse swinging motion, optimal control of sway damping by the transverse trolley 11 should be used since the movement of the sheave blocks 14, 15 is limited within a short stroke on the transverse trolley 11 and therefore can not deal with the large swinging motion. On the other hand, in order to damp the skew swinging motion, optimal control of sway damping by the sheave blocks 14 and 15 should be applied since the skew sway is relatively small and the movement of the transverse trolley 11 can not deal with this kind of motion, theoretically.

This allocation of tasks can be achieved by adjusting elements of the weighing matrix  $Q$ , specifically,  $q_2$ ,  $q_3$ ,  $q_4$  and  $q_5$  as follows:

The elements  $q_2$  and  $q_3$  are the weighing coefficients of the transverse movement component for the sheave blocks 14, 15, and if these elements are taken large, the transverse motion of the sheave blocks 14 and 15 required for damping transverse swinging motion will be limited. Therefore, only the trolley 11 will contribute to controlling the damping operation of transverse swinging motion.



The elements  $q_4$  and  $q_5$  are the weighing coefficients of the skew movement component for the sheave blocks 14, 15, and if these elements are taken small, the movement of the sheave blocks 14 and 15 required for damping skew swinging motion can be secured within the stroke ranges of the sheave blocks 14 and 15. Further, since the transverse trolley 11 cannot contribute to the skew movement theoretically, only the sheave blocks will effectively control the damping operation of skew swinging motion.

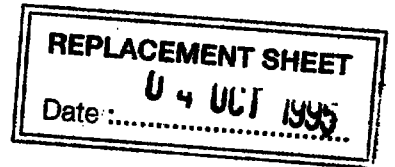
3) Next, with  $x = T^{-1} \times x$  substituted in the above equation [12], the following equation [13] can be obtained. This allows the system to obtain an optimal gain  $K = K' \times T^{-1}$  for the feed-back condition quantity  $x$ .

$$u = K' \times T^{-1} \times x = K \times x \quad \dots[13]$$

The optimal gain thus obtained by the above calculation is set up as an optimal gain part K.

(2) Then, in the same manner as in the first embodiment, the moving condition quantities and the transverse notch-driving control quantity detected by the detectors 31 through 38 and 40 are outputted to the controller 61.

(3) From the moving condition quantities and transverse notch-driving control quantity inputted, the controller 61 makes the optimizing control unit 63 effect the calculation of sway-damping optimizing control based on the aforementioned equation [1] to determine the velocity command



u0 for the transverse trolley 11 and velocity commands u1 and u2 for respective (left and right) sheave blocks 14 and 15.

(4) The optimizing control unit 63, based on the optimal gain K, calculates optimal controlling quantities in conformity with the moving condition quantities and operating condition detected by the detectors 31 through 38 and 40 and outputs the obtained optimal controlling quantities as control command signals for velocity commands u0, u1 and u2 to the drivers 17, 18 and 19 for the transverse trolley 11 and the two (left and right) sheave blocks 14 and 15, whereby the hoisted load-piece 23 is optimally controlled to stop swinging.

Thus, with the controller 61 illustrated in the third embodiment, the condition quantity vector x obtained from the detectors 31 through 38 and 40 is multiplied by the mode transforming matrix  $T^{-1}$  to produce a new condition quantity vector x' in which the transverse swinging component and the skew swinging component are separated. The thus newly produced vector x' is multiplied by the optimal gain K' to obtain optimal controlling quantity vector u. As to the damping operation, the optimizing control unit 63 is constructed such that the transverse swinging component is damped by the drive of the transverse trolley 11 while the skew swinging component is damped by the drive of the sheave blocks 14 and 15. In the prior art system, it was very



difficult for the operator to designate how to control the transverse trolley 11 and/or the sheave blocks 14, 15, but it is possible for this embodiment to solve the conventional problem of this kind.

5           Fig.5 shows a control block representing a fourth embodiment of a swaying hoisted load-piece damping control apparatus of the present invention.

          As shown in Fig.5, a controller 71 of this embodiment is has combined features of the controllers 51 and 62  
10       described in the second and third embodiments.

          Specifically, in the controller 71, an optimizing control unit 72, as receiving detection signals from the detectors 31 through 38 and 40, sets up optimal controlling qualities always referring to an optimal gain K which is  
15       determined according to both the operating condition and swinging modes (i.e., the transverse swinging motion and the skew swinging motion) as executed in the controllers 51 and 61 of the second and third embodiments. With the thus determined optimal controlling quantities, the controller 71  
20       effects sway-damping control.

          Now, description will be made on a specific sway-damping process effected by the controller 71 of this embodiment.

(1)       In the same manner as in the above-described third  
25       embodiment, the optimal-gain calculating unit 62 for

independently controlling transverse sway and skew sway derives the aforementioned state equation [10]. Then, optimal gains  $K_1$ ,  $K_2$  and  $K_3$  are determined in the same manner as described in the second embodiment, so that the

5      aforementioned three evaluation functions  $J_1$ ,  $J_2$  and  $J_3$  shown in [8] may be minimized. Here, weighing matrices  $Q_1$ ,  $Q_2$  and  $Q_3$  use those shown in the second embodiment. As to  $Q_1$  and  $Q_2$ ,  $q_2$ ,  $q_3$ ,  $q_4$  and  $q_5$  should be adjusted as shown in the third embodiment, so that the optimal gains  $K_1$  and  $K_2$  should allow

10     independent control operations, that is, control of the trolley 11 for transverse sway and control of the sheave blocks 14, 15 for skew sway can be done independently.

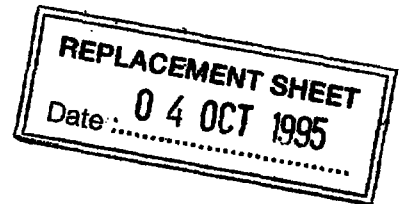
(2) As the following procedures are effected in the same manner as in the second embodiment, the detailed description

15     is omitted.

Thus, with the controller 71 illustrated in the fourth embodiment, the condition quantity vector  $x$  obtained from the detectors 31 through 38 and 40 is multiplied by the mode transforming matrix  $T^{-1}$  to produce a new condition quantity

20     vector  $x'$  in which the transverse swinging component and the skew swinging component are separated. The thus newly produced vector  $x'$  is multiplied by the optimal gain  $K'$  to obtain an optimal controlling quantity vector  $u$ . As to the damping operation, the optimizing control unit 72 is

25     constructed such that the transverse swinging component is



damped by the drive of the transverse trolley 11 while the skew swinging component is damped by the drive of the sheave blocks 14 and 15. In the prior art system, it was very difficult for the operator to designate how to control the transverse trolley 11 and/or the sheave blocks 14, 15, but it is possible for this embodiment to fix the conventional problem of this kind.

Further, it is possible to eliminate the difficulties in the operating-condition classifying determination and the operation control in the conventional configuration by determining the operating condition of the transverse trolley 11 by the operating condition determining unit 52, allowing the operating-condition-classifying optimal-gain selecting unit 53 to select an individual optimal gain  $K$  for each mode selected from the velocity following mode, the target-position reaching mode and the sway-damping mode using the sheave blocks 14 and 15, in correspondence with the operating condition of the transverse trolley 11, and making the optimizing control unit 72 effect optimal control of damping sway based on the selected optimal gain  $K$ .

As has been described in detail referring to the embodiments, the first feature of the swaying hoisted load-piece damping control apparatus of the present invention is equipped with a transverse trolley having a pair of sheave blocks which are disposed on both sides of the transverse



trolley and movable relative to the transverse trolley and further comprises: different kinds of detectors such as for detecting moving condition quantities of the transverse trolley, detecting moving condition quantities on right and left sides of the load-piece and detecting moving condition quantities of the right and left sheave blocks; a transverse notch-driving control quantity detector provided on an operation controlling panel; and a controller for effecting sway-damping control of a load-piece hoisting device based on detection signals obtained from the detectors, and is constructed such that the controller has an optimizing control unit which sets up optimal controlling quantities for the hoisted load-piece in accordance with moving condition quantities and notch-driving control quantity detected from the detectors, on the basis of a preset optimal gain for sway damping, and performs sway-damping control by driving the transverse trolley and the sheave blocks by the setup optimal controlling quantities. Therefore, it is possible to establish easy sway-damping control of the hoisted load piece in an assured manner by automating the sway-damping control of the hoisted load-piece which has been difficult in the prior art. Further, it is possible to realize the optimal sway-damping control which can damp the sway of the hoisted load-piece as fast as possible and to inhibit the load-piece from swinging. As a result, the work amount of the operator



as well as the time required for sway damping can be markedly decreased, thereby making it possible to improve the conveying efficiency of hoisted load-pieces.

In accordance with the second feature of the swaying  
5 hoisted load-piece damping control apparatus of the present  
invention, the controller comprises: an operating condition  
determining unit which detects the operating condition of the  
transverse trolley, based on detected signals of the  
operating condition quantities and the notch-driving control  
10 quantity for the transverse trolley; an operating-condition-  
classifying optimal-gain selecting unit which, in accordance  
with the operating condition detected by the operating  
condition determining unit, selects an operating-condition-  
classifying optimal gain for sway damping; and an optimizing  
15 control unit which, based on the optimal gain outputted from  
the operating-condition-classifying optimal-gain selecting  
unit, sets up optimal controlling quantities for the hoisted  
load-piece and performs sway-damping control by driving the  
transverse trolley and the sheave blocks in accordance with  
20 the setup optimal controlling quantities. Therefore, it  
becomes possible to set up an optimal gain by surely  
determining the operating condition of the trolley as to be  
in a state of the transverse travel, in a state of retarding  
travel or in a state of stopping and requiring sway-damping  
25 operation. As a result, it is possible to simplify the

determination of the operating condition and its operating control.

In accordance with the third feature of the swaying hoisted load-piece damping control apparatus of the present invention, the controller comprises: an independently  
5 controlling optimal-gain calculating unit which calculates independent optimal gains used to control transverse sway and skew sway of the hoisted load-piece, independently one from the other and outputs the calculated optimal gains; and an  
10 optimizing control unit for effecting sway-damping control which, based on the optimal gains outputted from the independently controlling optimal-gain calculating unit, sets up optimal controlling quantities for hoisted load-piece and effects sway-damping control by driving the transverse  
15 trolley to damp transverse sway of the load-piece and driving the right and left sheave blocks to damp skew sway of the load-piece. Therefore, it becomes possible to damp and inhibit the transverse sway and skew sway of the hoisted load-piece separately one from the other, and consequently,  
20 it is possible to establish proper control of driving the transverse trolley and sheave blocks in order to effect optimal sway-damping.

In accordance with the fourth feature of the swaying hoisted load-piece damping control apparatus of the present  
25 invention, the controller comprises: an independently

controlling optimal-gain calculating unit which calculates independent optimal gains used to control transverse sway and skew sway of the hoisted load-piece, independently one from the other and outputs the calculated optimal gains; an

5 operating condition determining unit which detects the operating condition of the transverse trolley, based on detected signals of the operating condition quantities and the notch-driving control quantity for the transverse trolley; an operating-condition-classifying optimal-gain

10 selecting unit which, in accordance with the operating condition detected by the operating condition determining unit, selects a preset operating-condition-classifying optimal gain or an operating-condition-classifying optimal gain set up by the independently controlling optimal-gain

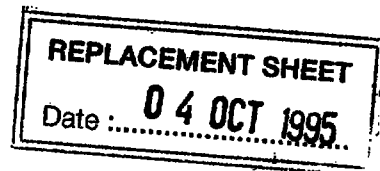
15 calculating unit and outputs the selected gain; and an optimizing control unit which, based on the optimal gain outputted from the operating-condition-classifying optimal-gain selecting unit, sets up optimal controlling quantities for the hoisted load-piece and performs sway-damping control

20 by driving the transverse trolley and the sheave blocks in accordance with the setup optimal controlling quantities. Therefore, it becomes possible to set up an optimal gain in accordance with the operating condition of the transverse trolley and the swinging condition of the hoisted load-piece.

25 As a result, it is possible to simplify the determination of

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the operating condition and its operating control. Further, it is possible to establish proper control of driving the transverse trolley and sheave blocks in order to effect optimal sway-damping.



## 6. CLAIMS

(1) A swaying hoisted load-piece damping control apparatus for use in a load-piece hoisting device having a transverse trolley for hoisting a load-piece, and a pair of, or right and left, sheave blocks which are disposed along moving directions of said transverse trolley in parallel with the sides of said transverse trolley and movable relative to said transverse trolley, comprising:

trolley moving condition quantity detectors for detecting moving condition quantities of said transverse trolley;

hoisted load-piece moving condition quantity detectors for detecting moving condition quantities on right and left sides of the load-piece hoisted by said transverse trolley;

sheave-block moving condition quantity detectors for detecting moving condition quantities of said right and left sheave blocks;

a notch-driving control quantity detector for detecting transverse notch-driving control quantity of said trolley controlled by means of an operation controlling panel; and

a controller for effecting sway-damping control of said load-piece hoisting device based on detection signals obtained from said detectors,

characterized in that said controller has an optimizing control unit which sets up optimal controlling quantities for



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the hoisted load-piece in accordance with moving condition quantities and notch-driving control quantity detected from said detectors, on the basis of a preset optimal gain for sway damping, and performs sway-damping control by driving said transverse trolley and said sheave blocks in accordance with the setup optimal controlling quantities.

2. A swaying hoisted load-piece damping control apparatus according to Claim 1 wherein said controller comprises: an operating condition determining unit which detects the operating condition of said transverse trolley, based on detected signals of the operating condition quantities and the notch-driving control quantity for said transverse trolley; an operating-condition-classifying optimal-gain selecting unit which, in accordance with the operating condition detected by said operating condition determining unit, selects an operating-condition-classifying optimal gain for sway damping from a plurality of predetermined optimal gains; and an optimizing control unit which, based on the optimal gain outputted from said operating-condition-classifying optimal-gain selecting unit, sets up optimal controlling quantities for the hoisted load-piece and performs sway-damping control by driving said transverse trolley and said sheave blocks in accordance with the setup optimal controlling quantities.

3. A swaying hoisted load-piece damping control apparatus



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according to Claim 1 wherein said controller comprises: an independently controlling optimal-gain calculating unit which calculates independent optimal gains used to control transverse sway and skew sway of the hoisted load-piece, independently one from the other and outputs the calculated optimal gains; and an optimizing control unit for effecting sway-damping control which, based on the optimal gains outputted from said independently controlling optimal-gain calculating unit, sets up optimal controlling quantities for hoisted load-piece and performs sway-damping control by driving said transverse trolley to damp transverse sway of the load-piece and driving said right and left sheave blocks to damp skew sway of the load-piece.

4. A swaying hoisted load-piece damping control apparatus according to Claim 1 wherein said controller comprises: an independently controlling optimal-gain calculating unit which calculates independent optimal gains used to control transverse sway and skew sway of the hoisted load-piece, independently one from the other and outputs the calculated optimal gains; an operating condition determining unit which detects the operating condition of said transverse trolley, based on detected signals of the operating condition quantities and the notch-driving control quantity for said transverse trolley; an operating-condition-classifying optimal-gain selecting unit which, in accordance with the



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| REPLACEMENT SHEET  |
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operating condition detected by said operating condition determining unit, selects a preset operating-condition-classifying optimal gain or an operating-condition-classifying optimal gain set up by said independently controlling optimal-gain calculating unit and outputs the selected gain; and an optimizing control unit which, based on the optimal gain outputted from said operating-condition-classifying optimal-gain selecting unit, sets up optimal controlling quantities for the hoisted load-piece and performs sway-damping control by driving said transverse trolley and said sheave in accordance with the setup optimal controlling quantities.



REPLACEMENT SHEET

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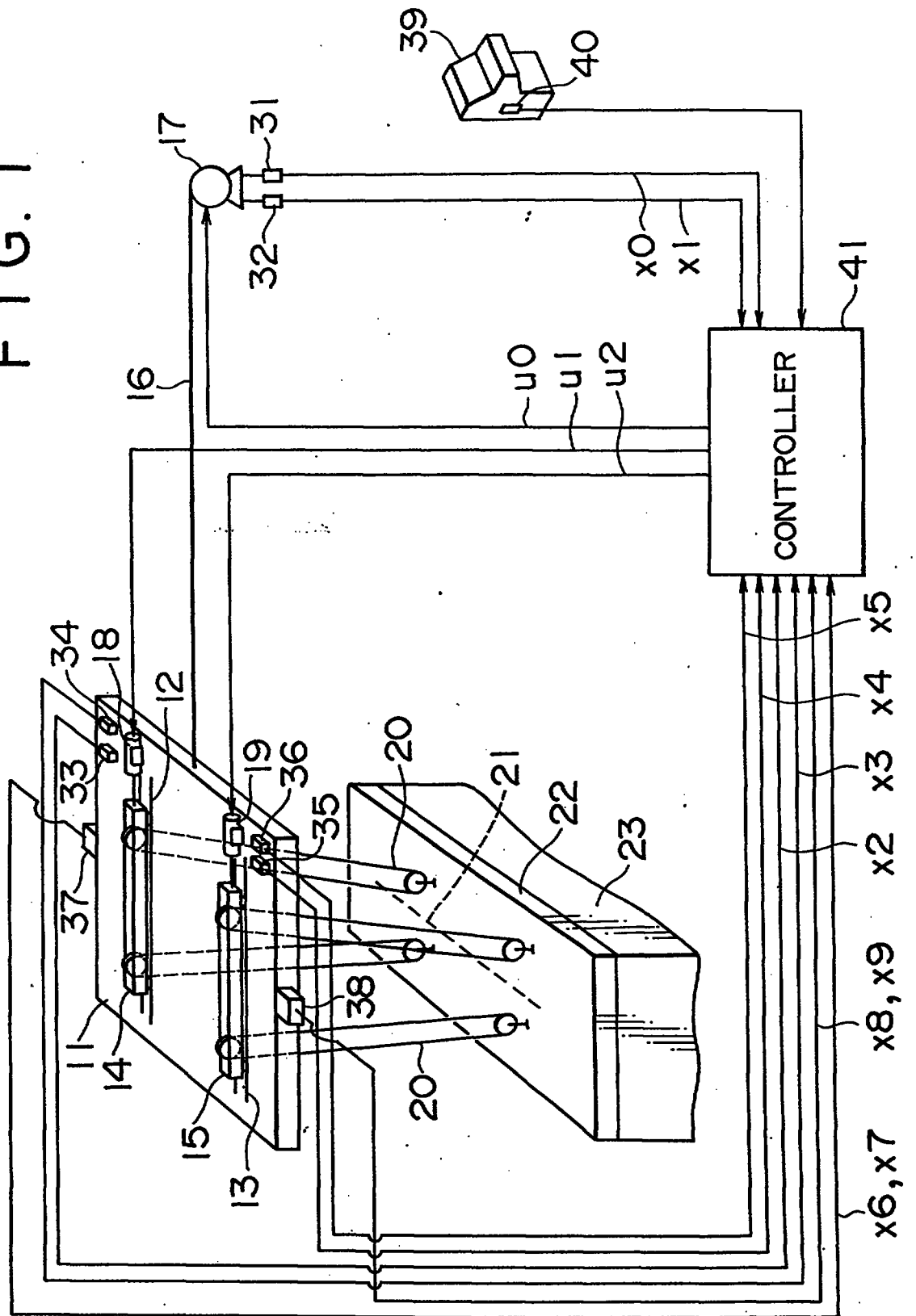
## 7. ABSTRACT

This Sheet Has Been Replaced

A SWAYING HOISTED LOAD-PIECE DAMPING CONTROL APPARATUS

A pair of sheave blocks 14, 15 which is movable relative to a transverse trolley 11 are disposed on both (right and left) sides of a transverse trolley 11. Detectors 31 through 38 are provided which detect the moving condition quantity of the transverse trolley 11, the moving condition quantities of a hoisted load-piece 23 on both (right and left) sides and the moving condition quantities of the two sheave blocks 14, 15 while a transverse notch-driving control quantity detector 40 is provided on an operation control panel 39 for the transverse trolley 11. A controller is provided which effects sway-damping control of the load-piece hoisting device based on detection signals obtained from the detectors 31 through 38 and 40, and an optimizing control unit performs sway-damping control with optimal controlling quantities on the basis of a preset optimal gain  $K$  in accordance with the moving condition quantities and the notch-driving control quantity.

FIG. 1



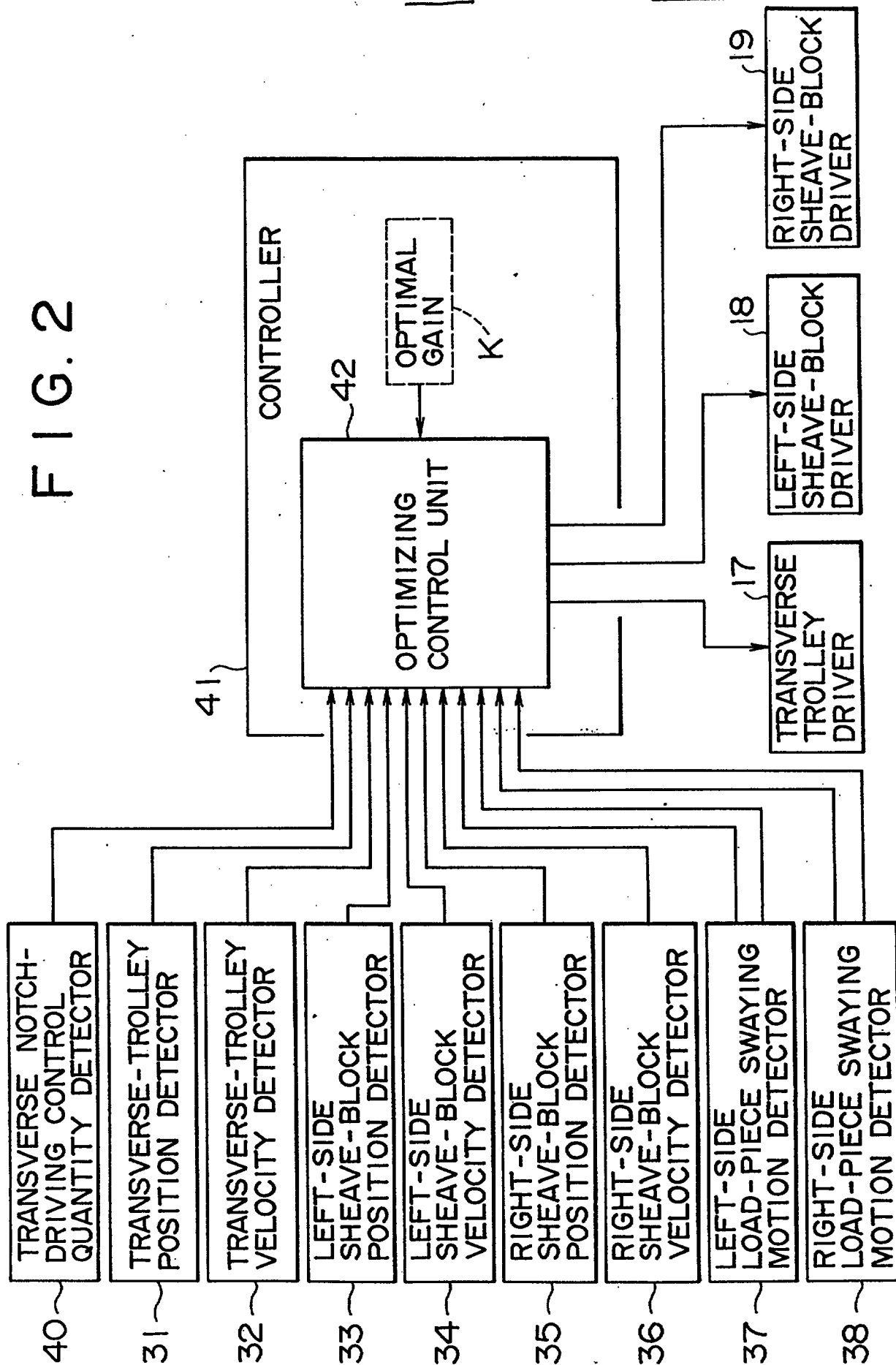
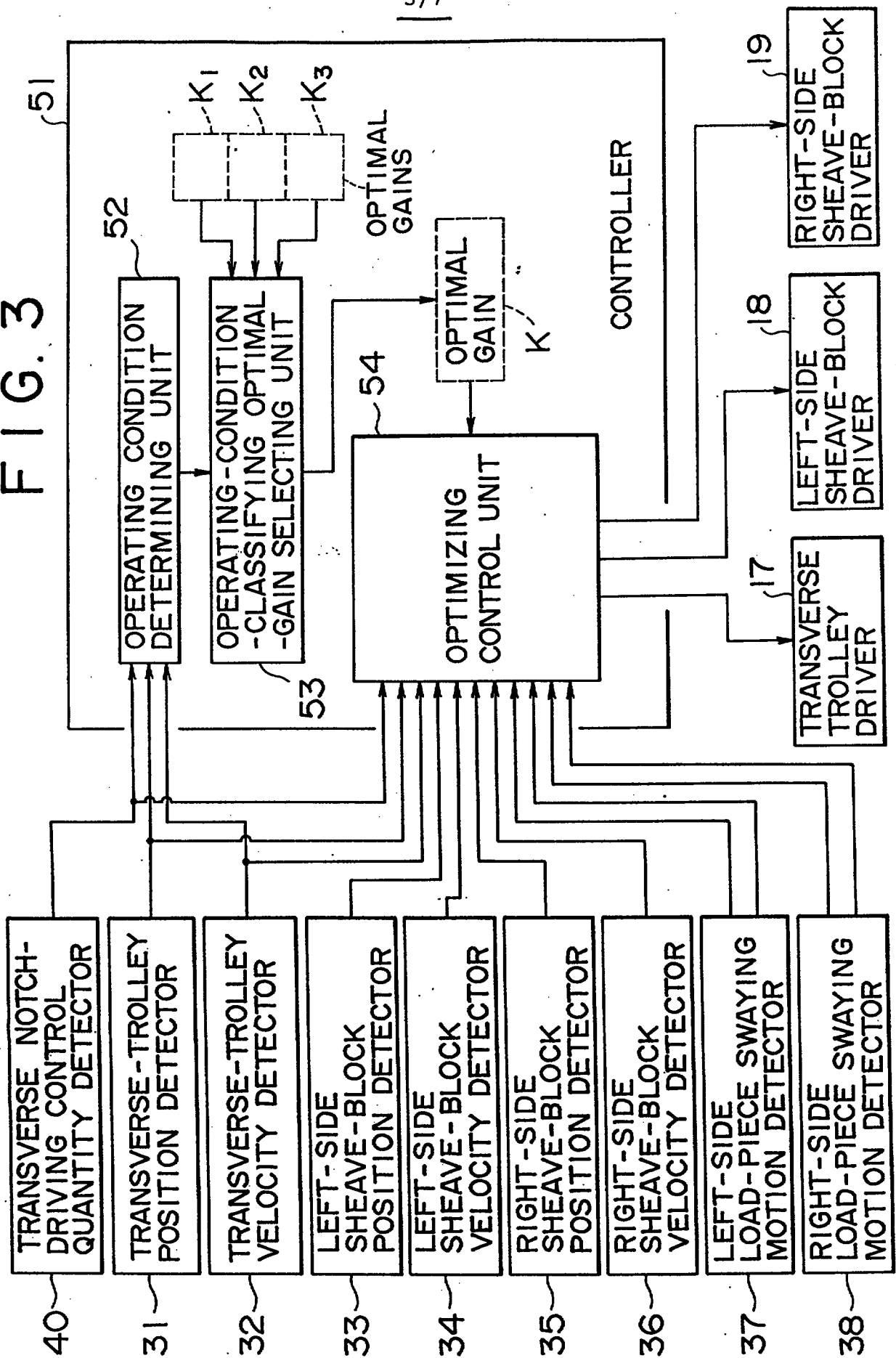
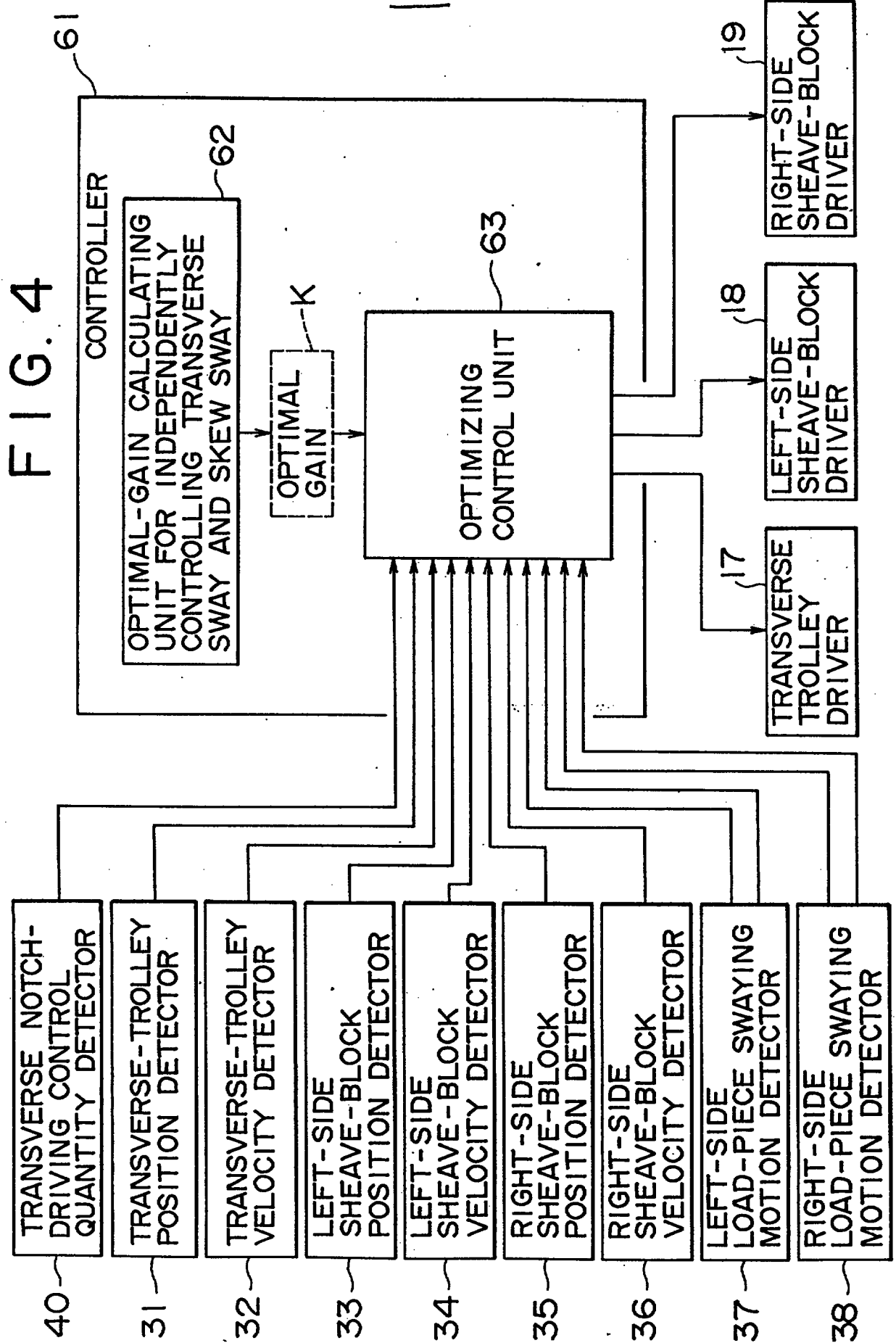


FIG. 3





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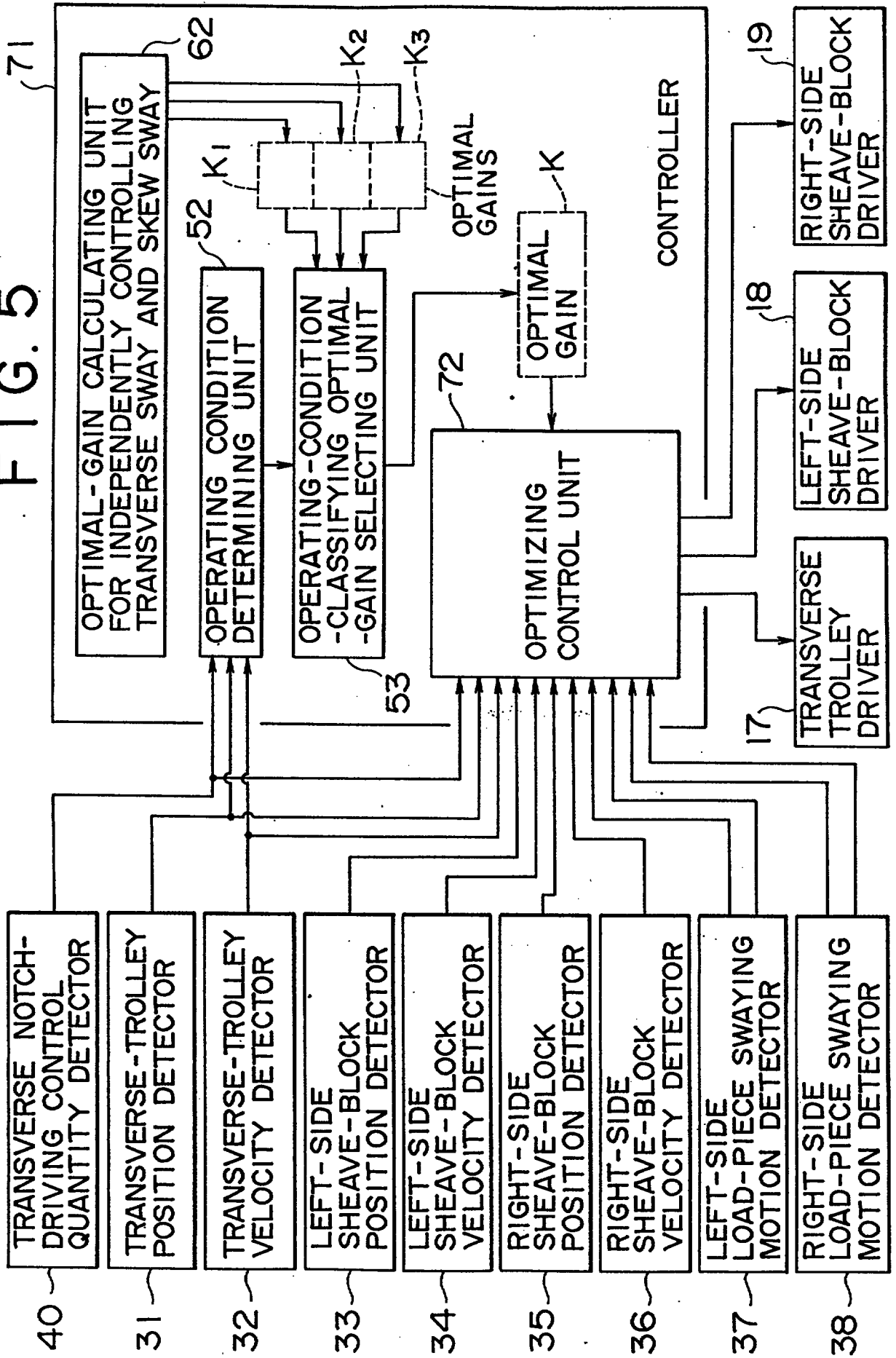


FIG. 6

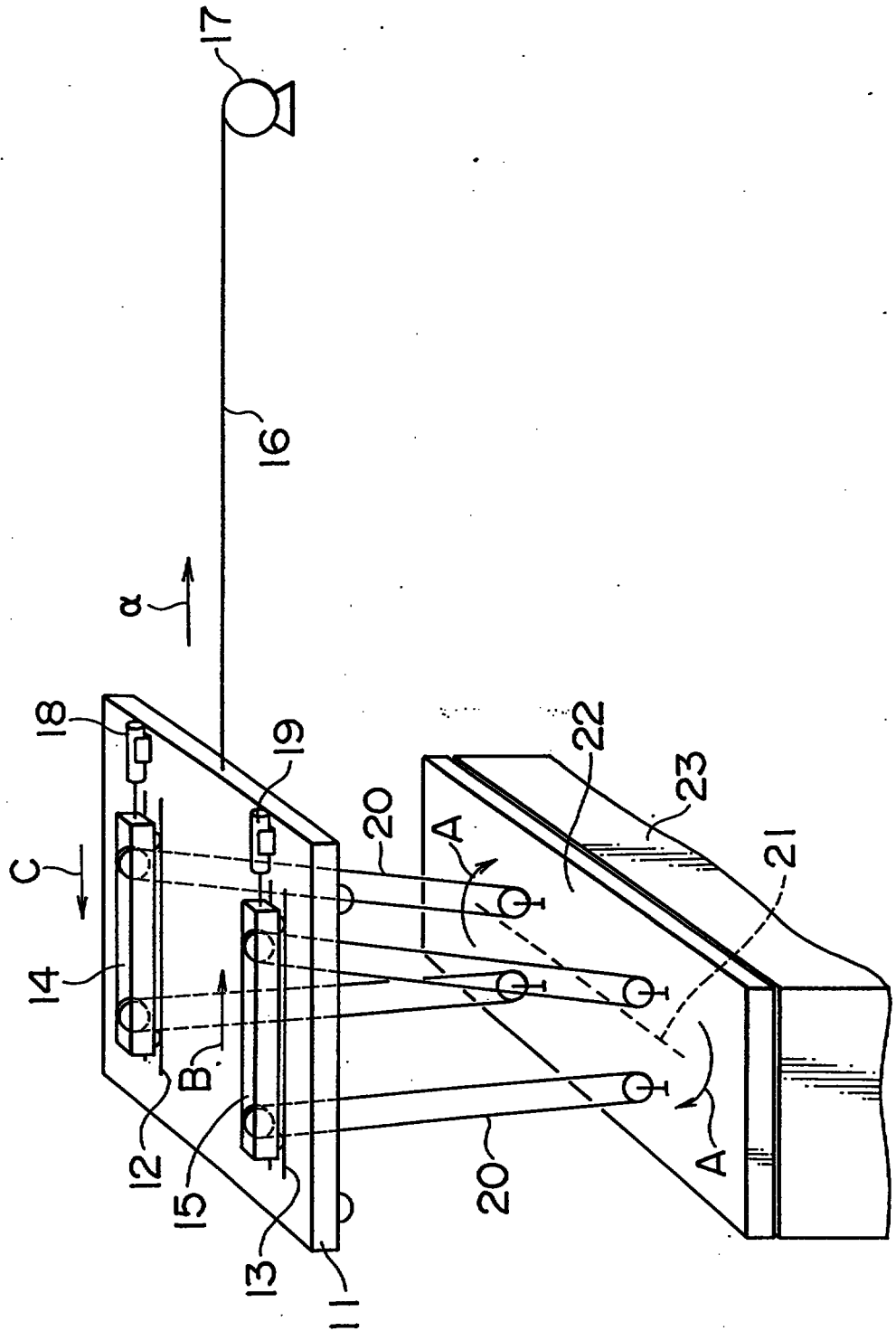


FIG. 7a

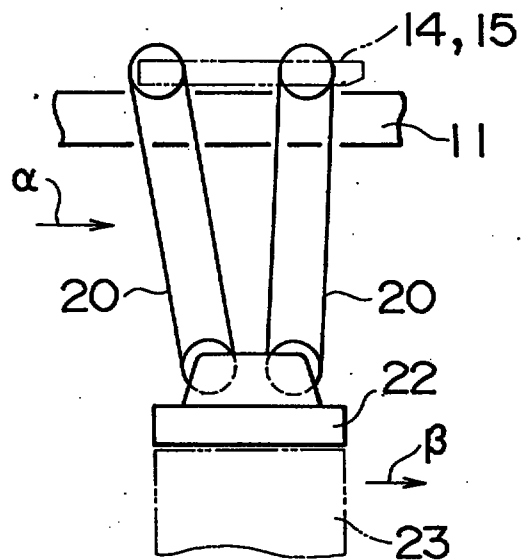


FIG. 7b

