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(71) Applicant: Mitsubishi Heavy Industries, Ltd.  
Tokyo (JP)

(72) Inventors:

- Toyohara, Takashi, Mitsubishi Heavy Ind., Ltd.  
Hiroshima-shi, Hiroshima (JP)

- Kouno, Susumu, Mitsubishi Heavy Ind., Ltd.  
Hiroshima-shi, Hiroshima (JP)

- Hoshina, Hiromitsu, Mitsubishi Heavy Ind., Ltd.  
Hiroshima-shi, Hiroshima (JP)

(74) Representative:

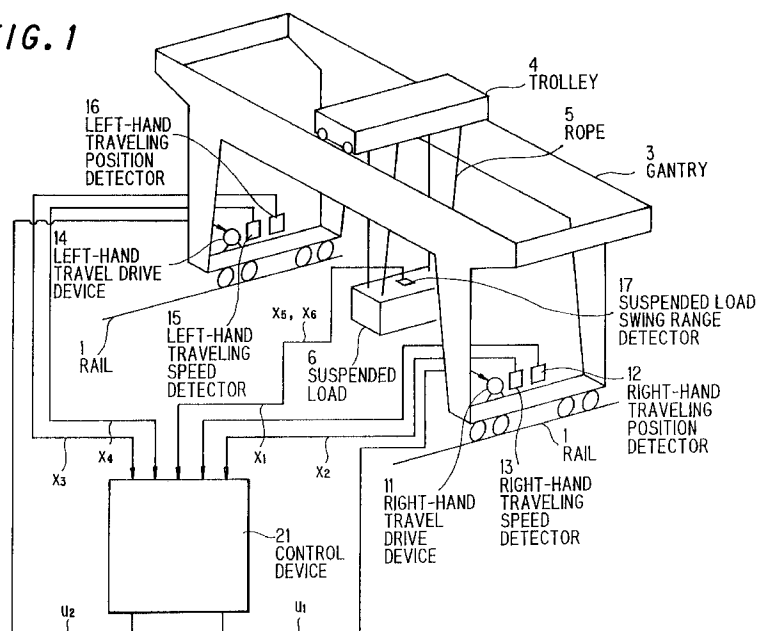
Cross, Rupert Edward Blount et al  
BOULT WADE TENNANT,  
27 Furnival Street  
London EC4A 1PQ (GB)

## (54) Suspended load steadying/positioning control device

(57) A suspended load steadying/positioning control device comprises independent drive devices 11, 14 for moving a crane 4 on two rails 1, the crane suspending a load by a rope 5 or the like and traveling on the rails 1 across them; position detectors 12, 15 for detecting the traveling position of the crane on each rail 1; speed detectors 13, 16 for detecting the traveling speed of the crane on each rail 1; a suspended load swing displacement detector 17; and an arithmetic means 21 for

calculating, based on inputs, operation commands for the drive devices 11, 14 at two locations, the inputs being the measured values of the traveling positions at two locations by the position detectors 12, 15, the measured values of the speeds at two locations by the speed detectors 13, 16, and the measured value of the displacement of the suspended load by the suspended load swing displacement detector 17. Thus, the suspended load can be accurately positioned even in a crane having a structural deformation.

FIG. 1



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**Description****BACKGROUND OF THE INVENTION**

5 This invention relates to a steadying (i.e., swing stopping)/positioning control device for performing the steadying and positioning of a suspended load in a crane.

The structure of a conventional crane is shown in Fig. 3.

As shown in Fig. 3, a gantry 3 is placed movably across two rails 1 (right and left rails) laid on the ground. Independent travel drive devices 11, 14 are provided for moving the gantry 3 on each rail 1. The travel drive devices 11, 14 are electrically connected to a control device 21, while the control device 21 produces an operation command for each of the travel drive devices 11, 14.

On the gantry 3, a trolley 4 is borne so as to be movable transversely. From the trolley 4, a rope 5 hangs down to suspend a load 6.

When an automatic run is to be made in such a crane, it is necessary to position the suspended load 6 accurately with respect to the traveling direction of the gantry 3, and cause the suspended load 6 to rest at a predetermined position.

For this purpose, the gantry 3 must be positioned at a given target position, and control for steadying the suspended load 6 must be performed simultaneously.

Thus, a control system is provided for receiving feedback on the traveling position and traveling speed of the gantry 3 as well as the swing state of the suspended load, and determining the amount of operation (such as speed command) of the drive devices for the gantry 3.

That is, a traveling position detector 12 and a traveling speed detector 13 are provided for detecting the traveling position  $x_1$  and traveling speed  $x_2$ , respectively, of the gantry 3 on the right rail 1 in Fig. 3. To the suspended load 6, a swing motion detector 17 is attached for detecting swing states, i.e., a swing displacement  $x_5$  of the suspended load and a swing speed  $x_6$  of the suspended load.

The control device 21 receives inputs of the measured values  $x_1$ ,  $x_2$ ,  $x_5$  and  $x_6$  by the detectors 12, 13 and 17, as shown in Fig. 4. By control computation, the control device 21 determines the amount of operation of the travel drive devices 11, 14, and carries out control.

In regard to control computation to be performed by the control device 21, it is known that a control system for positioning of the gantry and steadying of the suspended load can be realized by building the gantry and the suspended load into a bogie-pendulum system model as shown in Fig. 5, and constructing an optimum regulator based on this model (reference: "Mechanical System Control" Paragraph 6.2, Furuta Katsuhisa et al., Ohm).

In recent years, cranes have tended to be upsized. Thus, misalignment between the right-hand traveling position and the left-hand traveling position associated with the structural deformation of the gantry 3 may increase. A demand for positioning accuracy in an automatic run is becoming so harsh that the influence of the misalignment between the right and left traveling positions on positioning accuracy cannot be ignored.

A conventional control system drives the right and left drive systems by the same command, and thus is unable to reduce the misalignment between the right and left traveling positions to zero. As a result, the positioning accuracy for the suspended load 6 lowers, posing the grave problem that at the worst, required positioning accuracy cannot be fulfilled.

**SUMMARY OF THE INVENTION**

According to a first aspect of the present invention there is provided a positioning/steadying control system which comprises traveling position detectors and traveling speed detectors for detecting the right and left traveling positions and traveling speeds, respectively, of a crane traveling on two rails across them, right and left independent drive devices, and an arithmetic means for determining the amounts of operation of the right and left drive devices based on the measured values from the detectors as inputs.

In a preferred embodiment the control system is so constructed as to have traveling position detectors and traveling speed detectors for detecting the right and left traveling positions and traveling speeds, respectively, of a crane traveling on two rails across them, and right and left independent drive devices, and to determine the amounts of operation of the right and left drive devices based on the measured values from the detectors as inputs. Thus, the control system can simultaneously perform positioning for the right and left traveling positions, and the steadying of the suspended load.

**BRIEF DESCRIPTION OF THE DRAWINGS**

Fig. 1 is a schematic view showing the overall construction of a steadying control device in accordance with an embodiment of the present invention;

Fig. 2 is a block diagram of the steadying control device in accordance with an embodiment of the present invention;  
 Fig. 3 is a schematic view showing the overall construction of a conventional steadying control device;  
 Fig. 4 is a block diagram of the conventional steadying control device; and  
 Fig. 5 is an explanatory drawing showing a model with a gantry and a suspended load.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

A suspended load steadying/positioning control device in accordance with an embodiment of the present invention is shown in Figs. 1 and 2. Fig. 1 is a schematic view showing the overall construction of the crane and control system according to the instant embodiment. Fig. 2 is a block diagram of the control device of this embodiment. The same parts as in the aforementioned example are assigned the same numerals and symbols, and explanations for them are omitted.

As shown in Fig. 1, the suspended load steadying/positioning control device of the instant embodiment is equipped with a right-hand traveling position detector 12 and a right-hand traveling speed detector 13 for detecting the traveling position  $x_1$  and traveling speed  $x_2$  of a gantry 4 on a right rail 1 in Fig. 1, and is also equipped with a left-hand traveling position detector 15 and a left-hand traveling speed detector 16 for detecting the traveling position  $x_3$  and traveling speed  $x_4$  of the gantry 4 on a left rail 1 in the drawing.

To detect the swing state of a suspended load 6, a swing motion detector 17 is mounted on the suspended load 6 to detect a swing displacement  $x_5$  and swing speed  $x_6$  of the suspended load 6 in the traveling direction by use of an accelerometer or the like.

The control device 21 receives inputs of detection signals  $x_1$ ,  $x_2$ ,  $x_3$ ,  $x_4$ ,  $x_5$  and  $x_6$  from the detectors 12, 13, 15, 16 and 17, computes the amounts of optimum operation necessary for returning to zero the entered motion state amounts, i.e., the right and left traveling positions and traveling speeds, the swing displacement and swing speed of the suspended load, and issues control command signals to the right and left travel drive devices 11, 14.

As shown in Fig. 2, an optimum steadying gain  $K$  is separately precalculated and preset in the control device 21. The control device 21 has a control arithmetic portion 22 which, based on this optimum gain  $K$ , computes the amounts of optimum operation in response to the right and left traveling positions and traveling speeds, the swing displacement and swing speed of the suspended load 6 that have been entered from the detectors 12, 13, 15, 16 and 17, and performs optimum steadying/positioning control by the right and left travel drive devices 11, 14.

The foregoing suspended load steadying/positioning control device concerned with the instant embodiment performs optimum steadying/positioning control by the following concrete processing steps (1) to (3):

(1) The detectors 12, 13, 15, 16 and 17 detect the traveling positions and traveling speeds of the right and left drive devices, as well as the motion state amount of the suspended load 6, and issues these data to the control device 21.

(2) Then, based on these motion state amounts, the optimum control portion 22 calculates speed commands  $u_1$ ,  $u_2$  for the right and left drive devices 11, 14 according to the computation of optimum steadying control using the following Numeric Expression 1:

$$u = Kx$$

where  $u$  represents an operation amount vector to be described below,  $u_1$  represents a speed command for the right-hand drive device 11, and  $u_2$  represents a speed command for the left-hand drive device 14. That is, the following Numeric Expression 2 holds:

$$u = [u_1 \ u_2]^T$$

In the Numeric Expression 1,  $x$  represents a state amount vector to be described below. Its elements are, in order of arrangement from left to right, a right-hand traveling position  $x_1$  and a right-hand traveling speed  $x_2$ , a left-hand traveling position  $x_3$  and a left-hand traveling speed  $x_4$ , a swing displacement  $x_5$  and a swing speed  $x_6$  of the suspended load. That is, the following Numeric Expression 3 holds:

$$x = [x_1 \ x_2 \ x_3 \ x_4 \ x_5 \ x_6]^T$$

Further,  $K$  represents a constants matrix with 2 rows and 6 columns shown below.

$$K = \begin{bmatrix} k_{11} & k_{12} & k_{13} & k_{14} & k_{15} & k_{16} \\ k_{21} & k_{22} & k_{23} & k_{24} & k_{25} & k_{26} \end{bmatrix}$$

The above constants matrix K is an optimum gain determined by the following procedure:

(a) From motion equations formulated for the right and left travel drive devices 11, 14, gantry 3, rope 5 and suspended load 6, a state equation (Numeric Expression 5) as indicated below, is derived. This state equation is a linear differential equation expressing the vibrations of the suspended load 6 as a spring-mass system.

$$\frac{d}{dt}x = Ax + Bu$$

where u and x represent the aforementioned operation amount vector and state amount vector, respectively, A represents a transition matrix with 6 rows and 6 columns, and B represents a drive matrix with 6 rows and 2 columns.

(b) For the above state equation (Numeric Expression 5), the optimum gain K of Numeric Expression 7 that minimizes an evaluation function J of Numeric Expression 6 below is sought.

$$J = \int_0^{\infty} (x^T Q x + u^T R u) dt$$

where Q and R represent weighting matrices with 6 rows and 6 columns and 2 rows and 2 columns, respectively.

$$u = Kx$$

By so minimizing the evaluation function J, the optimum gain K is found which rapidly reduces all elements of the state amount to zero with the smallest possible operation amount u.

(3) Based on the optimum gain K obtained by the above-described computation, the optimum control portion 22 determines optimum operation amounts adapted to the motion state amounts and the run state by the detectors 12, 13, 15, 16 and 17, and issues the optimal operation amounts as control command signals for the right and left drive devices 11, 14.

By driving them according to the signals, the optimum control portion 22 performs optimum control for positioning for the right and left traveling positions, and steadying of the suspended load 6.

Such optimum control can eliminate the misalignment between the right and left traveling positions, achieve the steadying of the suspended load, and ensure highly accurate positioning of the suspended load.

As described based on the embodiment, the present invention has traveling position detectors and traveling speed detectors for detecting the right and left traveling positions and traveling speeds, respectively, of a crane traveling on two rails across them, and right and left independent drive systems, and computes the amounts of operation of the drive devices by means of an optimum regulator. Thus, the invention permits the accurate positioning of a suspended load even in a crane having structural deformation.

## Claims

1. A suspended load steadying/positioning control device comprising:

independent drive devices for moving a crane on two rails, said crane suspending a load by a rope or the like and traveling on the rails across them;  
position detectors for detecting the traveling position of the crane on each rail;

speed detectors for detecting the traveling speed of the crane on each rail;  
a suspended load swing displacement detector; and  
arithmetic means for calculating, based on inputs, operation commands for the drive devices at two locations,  
said inputs being the measured values of the traveling positions at two locations by the position detectors, the  
measured values of the speeds at two locations by the speed detectors, and the measured value of the displacement of the suspended load by the suspended load swing displacement detector.

2. The suspended load steadying/positioning control device of claim 1, wherein based on an optimum steadying gain which has been calculated and set separately, the arithmetic means computes the amount of optimum operation in response to the right and left traveling positions and traveling speeds, the swing displacement and swing speed of the suspended load that have been entered from the detectors, and performs optimum steadying/positioning control by the drive devices.

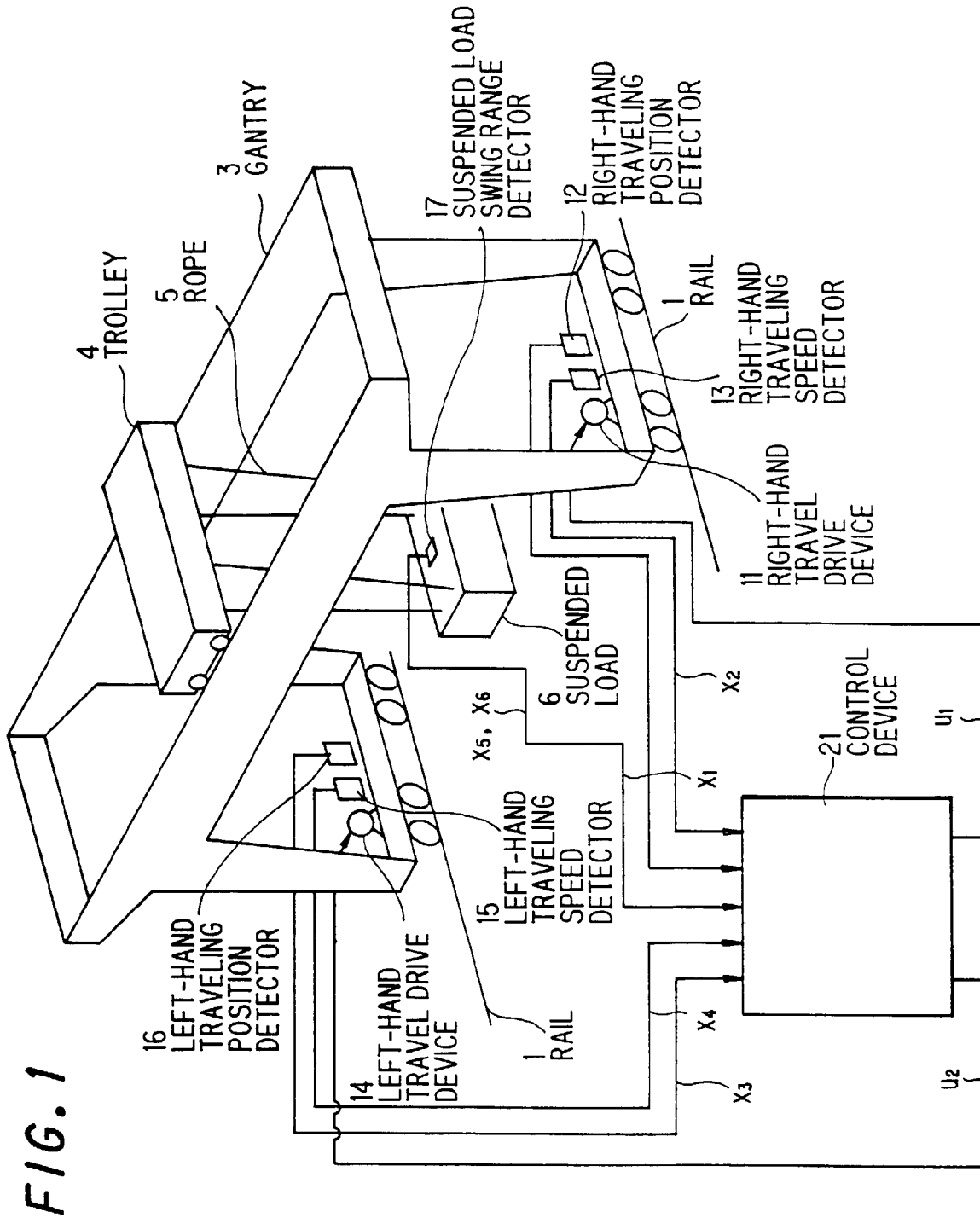
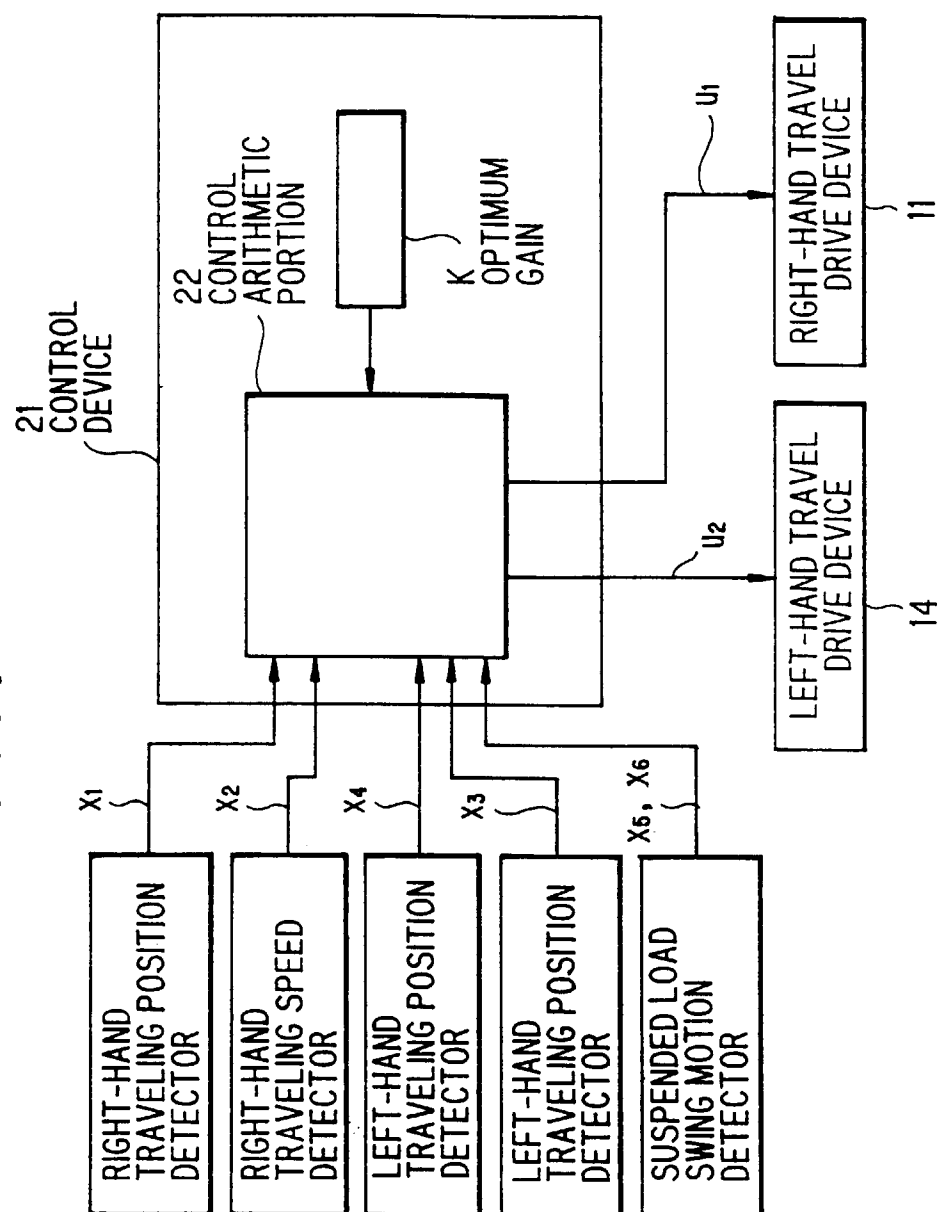


FIG. 2



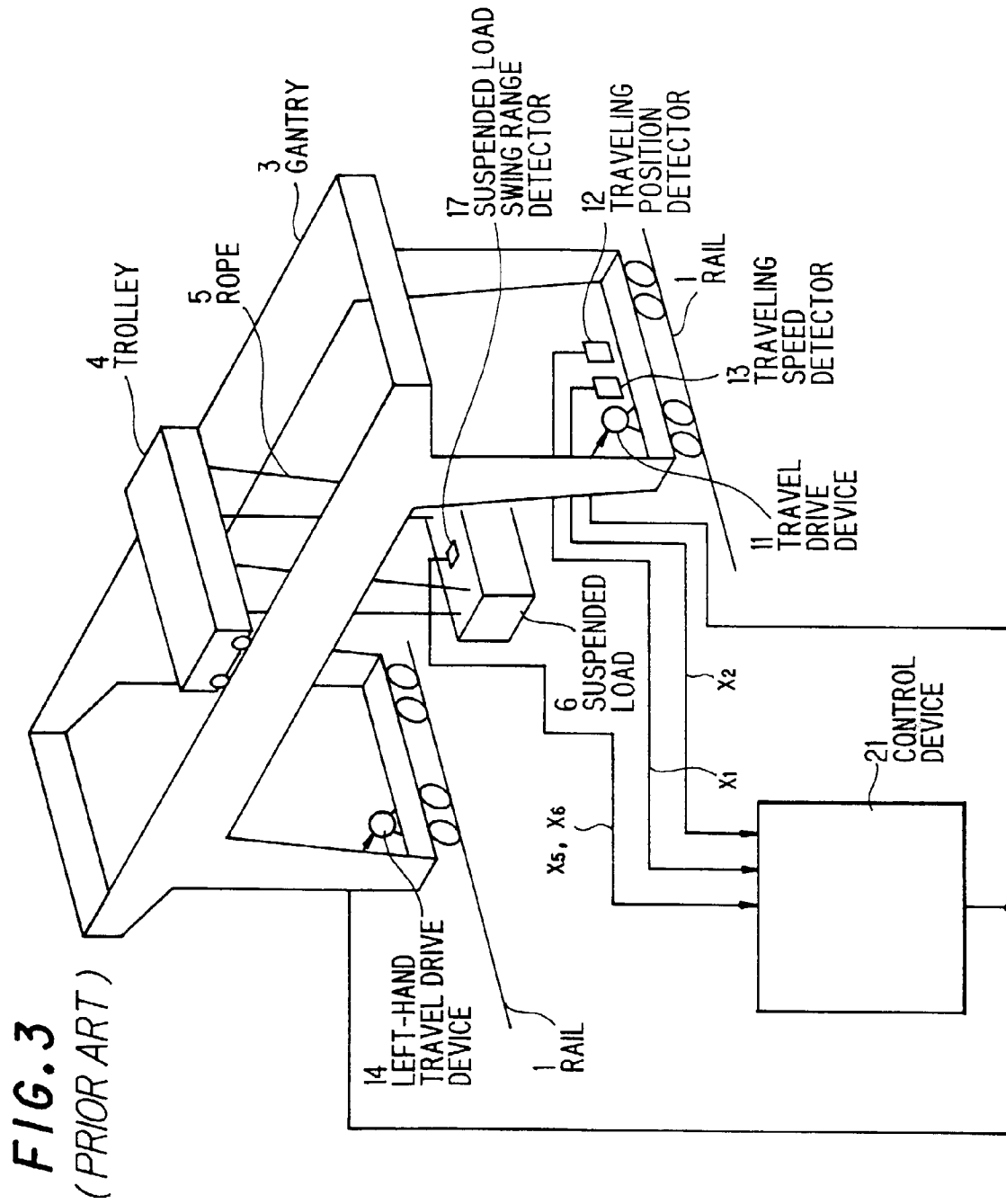
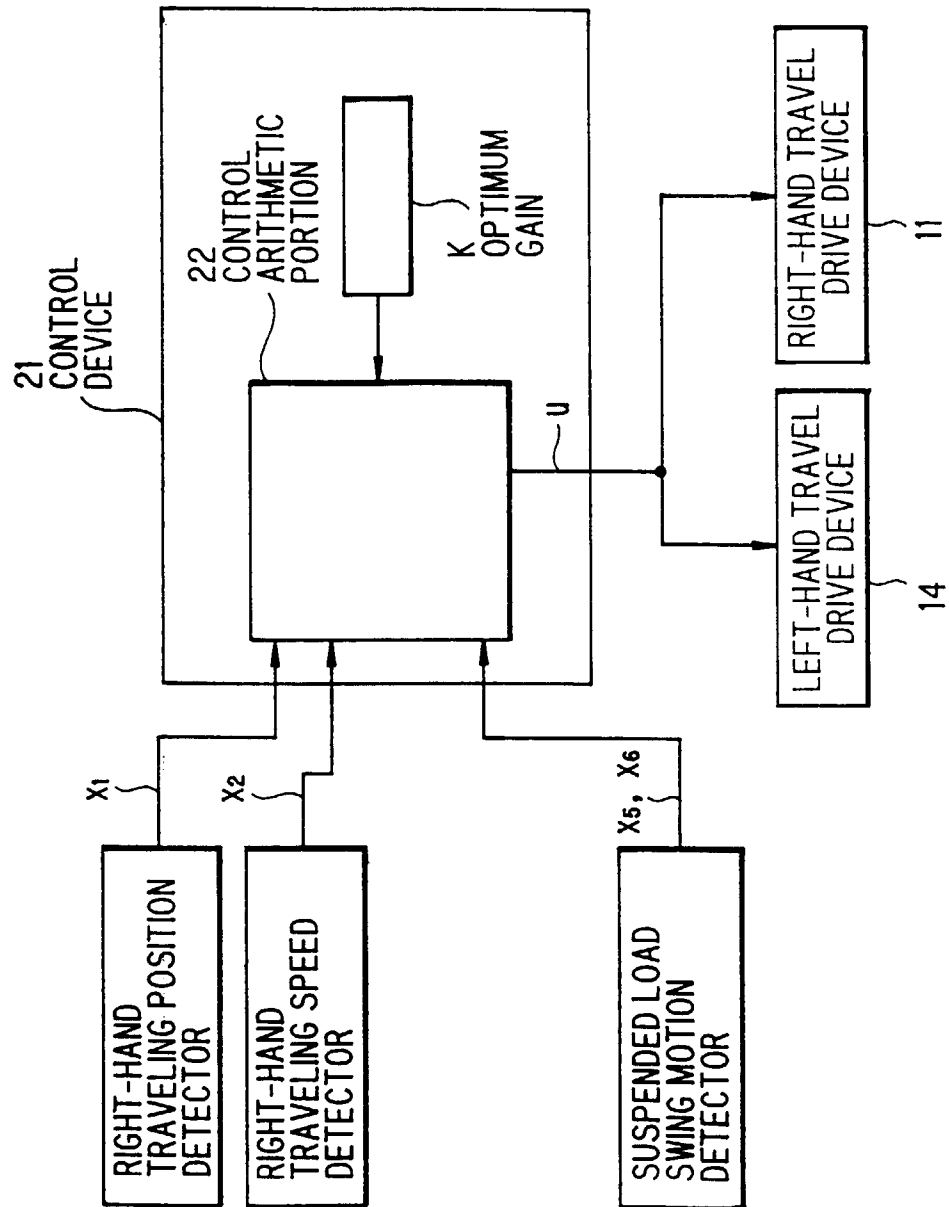


FIG. 4 (PRIOR ART)



*FIG. 5*

