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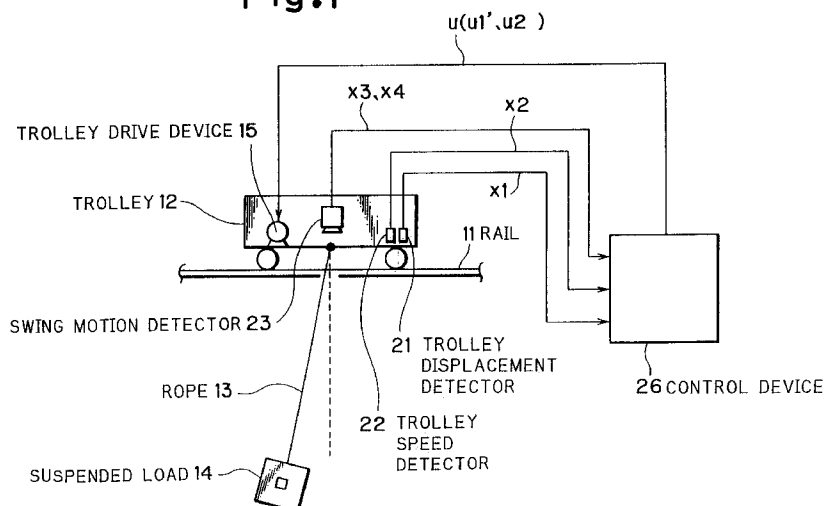
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(54) **Suspended load steadying control device**

(57) A trolley 12 travels along rails 11 while suspending a load 14 by a rope 13. The trolley 12 has a trolley displacement detector 21 for detecting a trolley position x_1 , a trolley speed detector 22 for detecting a trolley speed x_2 , and a swing motion detector 23 for detecting a swing displacement x_3 and a swing speed x_4 of the suspended load 14. A control device 26 produces a speed command u based on the detected values x_1 , x_2 , x_3 and x_4 . In response to the speed command u , a

trolley drive device 15 is driven to run the trolley 12. When the trolley is to be moved to the target position by the control of the control device 26, control for steadying the suspended load while the trolley 12 is following a set speed is performed in the first half of control. As the trolley 12 approaches the target position, control for positioning the trolley and steadying the suspended load is performed. Thus, the swing of the suspended load is lessened not only at the target position, but also during the travel of the trolley.

Fig.1**EP 0 841 294 A2**

Description**BACKGROUND OF THE INVENTION**

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

A conventional suspended load steadying control device will be described by reference to Fig. 5, a view showing an overall structure, Fig. 6, a block diagram of the control device, and Fig. 7 showing control characteristics.

As shown in Fig. 5, a trolley 012 can travel on rails 011 by the driving action of a trolley drive device 015. From the trolley 011, a rope 013 hangs down, and the trolley 011 transports a suspended load 014 by attaching the suspended load 014 to the front end of the rope 013.

The trolley 012 is further provided with a trolley displacement detector 021 for detecting a trolley position, x_1 , a trolley speed detector 022 for detecting a trolley speed, x_2 , and a swing motion detector 023 for detecting a swing displacement, x_3 , and a swing speed, x_4 .

The swing motion detector 023 is a detector of the type which photographs a marker attached to the suspended load 014 by means of a camera mounted on the trolley 012 vertically downwards, and image processes an image taken, thereby detecting the swing displacement x_3 and swing speed x_4 .

The trolley position x_1 , trolley speed x_2 , swing displacement x_3 and swing speed x_4 detected are sent to a control device 026. The control device 026 performs a positioning optimum control computation (to be described later on) by means of a built-in optimum control portion 032 (see Fig. 6), and produces a speed command, u . Under this speed command u , the trolley drive device 015 is driven to move the trolley 012.

When an automatic run is to be performed in such a crane, it is necessary to incorporate control for positioning the suspended load 014 exactly at a target position as instructed.

The crane can be modeled as a bogie-pendulum system, and it is known with such a model that the positioning of the suspended load can be realized by driving the trolley according to feedback control by an optimum regulator.

With reference to Figs. 6 and 7, a method for optimum control of the crane will be described. This control is performed by an optimum control portion (optimum regulator) 032 of a control device 026 which calculates the amount of operation (speed command, u , for the trolley in this embodiment) in accordance with the following control rule (Numeric Expression (1)):

$$u = Kx \quad (1)$$

where x represents a state amount vector to be described below, whose respective elements are, in order of arrangement from left to right, a trolley position x_1 , a trolley speed x_2 , a swing displacement x_3 and a swing speed x_4 of the suspended load. That is, the following Numeric Expression (2) holds.

$$x = [x_1 \ x_2 \ x_3 \ x_4]^T \quad (2)$$

Further, K represents a gain vector with 4 columns indicated in Numeric Expression (3).

$$K = [k_1 \ k_2 \ k_3 \ k_4] \quad (3)$$

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

(a) From motion equations formulated for the trolley-pendulum system motion model shown in Fig. 5, a state equation, Numeric Expression (4), is derived. This state equation is a linear differential equation expressing the vibrations of the suspended load 014 as a spring-mass system. An explanation for the state equation, including the way of deriving it, is omitted here.

$$\frac{d}{dt} x = Ax + Bu \quad (4)$$

where u and x represent the aforementioned amount of operation and state amount vector, respectively, A represents a transition matrix with 4 rows and 4 columns, and B represents a drive matrix with 4 rows and 1 column.

(b) For the above state equation, Numeric Expression (4), the optimum gain K of Numeric Expression (6) that minimizes an evaluation function J of Numeric Expression (5) below is sought.

$$J = \int_0^{\infty} (\mathbf{x}^T \mathbf{Q} \mathbf{x} + r u^2) dt \quad \text{----- (5)}$$

where Q is a weighting matrix with 4 rows and 4 columns, and r represents a weighting factor.

$$u = Kx \quad (6)$$

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 (speed command) u.

Based on the optimum gain K obtained by the above-described computation, the control arithmetic unit 026 determines the amount of optimum operation by the sum of the products of the motion state amounts by the detectors 021, 022, 023 and the optimum gain K. The control arithmetic unit 026 issues this amount of optimum operation as a control command signal (speed command u) for the trolley drive device 015. By driving this device according to the signal, optimum control is performed.

At this time, position signal input (trolley position x1) on the trolley 012 is given as feedback as a position relative to a trolley target position, pset, whereby the trolley 012 can be positioned at the target position. Simultaneously, the suspended load 014 can be steadied. Thus, the suspended load 014 can be brought to the given target position.

When such control is performed by the optimum regulator, the trolley is moved from a stop state with the target position being changed. On this occasion, at the initial stage of control, the trolley position is far away from the target position. Hence, the relative position x1 of the trolley as a state amount takes a large value compared with other state amounts. The speed command u as the amount of operation also takes a large value immediately after initiation of control. The speed command u immediately after start of control is depicted as a dotted line (from time 0 to T2) in Fig. 7.

On the other hand, the trolley in the initial state is at zero speed. In the actual crane, the acceleration and speed of the trolley are also restricted. This necessitates acceleration at a maximum acceleration (from time 0 to T1) and movement at maximum speed (from time T1 to T2) at the initial stage of control. The trolley speed x2 in this case is indicated by a solid line in Fig. 7.

That state of the trolley speed is effective for making the trolley reach the target position promptly, but it is a state in which no feedback on the swing state of the suspended load works. As a result, the trolley approaches the target position while retaining swings occurring as the trolley is accelerated.

This has posed the serious problems of not only diminishing safety during movement of the trolley, but also lengthening the settling time for positioning, thereby lowering the materials handling efficiency.

SUMMARY OF THE INVENTION

According to a first aspect of the present invention there is provided a suspended load steadying control device which performs, in addition to conventional optimum control, optimum control for carrying out steadying control while causing a trolley to follow a given speed command, and which has a switching device for switching between these two manners of control in accordance with the state of run.

In a currently preferred embodiment the suspended load steadying control device comprises:

a trolley motion state amount detector for detecting the motion state amount of a trolley in a crane suspending a load by a rope member;

a suspended load motion state amount detector for detecting the motion state amount of the load suspended by the trolley; and

a control device for performing steadying control of the suspended load based on detection signals introduced from the respective detectors;

the control device comprising:

a speed following optimum control portion for driving the trolley with the amount of optimum operation based on an optimum gain adjusted to follow a certain set speed, thereby performing steadying control;

a positioning optimum control portion for driving the trolley with the amount of optimum operation based on an optimum gain adjusted to position the trolley at a certain target position, thereby performing steadying control; and

a run state-wise control selection portion for selecting the speed following optimum control portion or the positioning

optimum control portion based on the run state amount of the trolley, to drive the trolley.

The trolley motion state amount detector may comprise a trolley displacement detector for detecting a trolley position, and a trolley speed detector for detecting a trolley speed.

The suspended load motion state amount detector may be a swing motion detector for detecting the swing displacement and swing speed of the suspended load.

The run state-wise control selection portion may be constructed as follows: When the relative position of the trolley to the target position is larger than a set value, the run state-wise control selection portion selects the speed following optimum control portion to drive the trolley. When the relative position of the trolley to the target position is smaller than the set value, on the other hand, the run state-wise control selection portion selects the positioning optimum control portion to drive the trolley.

According to the preferred embodiment, when the trolley is moved to a target position, control for performing steadying while causing the trolley to follow a set speed is carried out in the former half of control, whereby the swing of the suspended load can be kept small. When the trolley approaches the target position, this control is switched to conventional control for performing the positioning and steadying of the trolley. Thus, the swing of the suspended load at switching of control can be reduced, and the time to settlement of swing by the conventional control can be kept short.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is an overall structural view of a suspended load steadying control device according to an embodiment of the present invention;

Fig. 2 is a block diagram showing the suspended load steadying control device according to an embodiment of the present invention;

Fig. 3 is a flow chart showing the processings performed in a control device;

Fig. 4 is a characteristic view showing the control characteristics of a suspended load steadying control device embodying the present invention;

Fig. 5 is an overall structural view showing a conventional suspended load control device;

Fig. 6 is a block diagram showing a conventional suspended load steadying control device; and

Fig. 7 is a characteristic view showing the control characteristics of a conventional suspended load steadying control device.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Embodiments of the present invention will be described with reference to the appended drawings, in which Fig. 1 is an overall structural view, Fig. 2 is a block diagram of a control device, Fig. 3 is a flow chart showing a control action, and Fig. 4 is a control characteristics view.

As shown in Fig. 1, a trolley 12 can travel on rails 11 by the driving action of a trolley drive device 15. From the trolley 11, a rope 13 hangs down, and the trolley 11 transports a suspended load 14 by attaching the suspended load 14 to the front end of the rope 13.

The trolley 12 is further provided with a trolley displacement detector 21 for detecting a trolley position, x_1 , a trolley speed detector 22 for detecting a trolley speed, x_2 , and a swing motion detector 23 for detecting a swing displacement, x_3 , and a swing speed, x_4 .

The swing motion detector 23 is a detector of the type which photographs a marker attached to the suspended load 14 by means of a camera mounted on the trolley 12 vertically downwards, and image processes an image taken, thereby detecting the swing displacement x_3 and swing speed x_4 .

The trolley position x_1 , trolley speed x_2 , swing displacement x_3 and swing speed x_4 detected are sent to a control device 26. The control device 26 performs, in the first half of control, control for steadying the trolley 12 while causing it to follow a set speed, as will be described later on. This type of control is done by means of built-in optimum control portions 31, 32 (see Fig. 2). Thereby, the swing of the suspended load 14 is kept small (control added by the present invention). When the trolley 12 approaches the target position, this control is switched to control for positioning and steadying the trolley 12 (conventionally performed control). Under this speed command u , the trolley drive device 15 is driven to move the trolley 12.

In the control device 26, as shown in Fig. 2, there are disposed an acceleration/constant speed optimum control portion 31 for controlling the trolley 12 so as to follow a set speed, v_{set} , and a positioning optimum control portion 32 for performing control aimed at positioning and steadying the trolley.

The measured values detected by the detectors 21, 22, 23 are entered into these optimum control portions 31, 32. In regard to the trolley position, the relative position of the trolley to a target position, p_{set} , is to serve as control input. Thus, a relative position x_1' defined as

$$x1' = x1 - pset$$

is used as control input.

In regard to input to the acceleration/constant speed optimum control portion 31, the trolley speed will be the relative speed of the trolley to the set speed vset. Thus, a relative speed x2' defined as

$$x2' = x2 - vset$$

is used as an input signal for the optimum control portion 31.

Also, a speed command, u1, output from the acceleration/constant speed optimum control portion 31 is also the relative speed from the set speed. Thus, u1' defined as

$$u1' = u1 + vset$$

is used as the result of computation by the optimum control portion 31 (trolley speed command).

The processing performed by the acceleration/constant speed optimum control portion 31 is as follows: An optimum control gain is determined in the same way as for a conventional control gain. However, a gain to multiply the trolley position is unnecessary for control for causing following up to the set speed. Thus, a weighting matrix, Q', set such that the gain to multiply the trolley position will be zero is used, and an optimum gain, K', for minimizing the following evaluation function, J', is found.

$$J' = \int_0^{\infty} (x^T Q' x + r' u^2) dt \quad \text{--- (7)}$$

$$u = K'x + vset \quad (8)$$

The trolley speed command u1', the output signal, has the set speed vset added as stated above.

The positioning optimum control portion 32 does the same computation as a conventional optimum control portion 032 as shown in Fig. 6, thereby to produce a trolley speed command u2 for positioning and steadying the trolley.

A run state-wise control selection portion 33 receives inputs of the trolley speed command u1' from the acceleration/constant speed optimum control portion 31, the trolley speed command u2 calculated by the positioning optimum control portion 32, and the relative position x1' to the target position pset for the trolley 12. The run state-wise control selection portion 33 performs switching so as to issue the results of the acceleration/constant speed optimum control portion 31 (trolley speed command) u1' as a speed command, u, if the relative position x1' to the target position pset for the trolley 12 is greater than a certain set value; or to issue the trolley speed command u2, the results of the positioning optimum control portion 32, as a speed command, u, if the relative position x1' is smaller than the certain set value.

The speed command u1' or the speed command u2 selected by the run state-wise control selection portion 33 is issued to the trolley drive device 15 to drive the trolley 12.

The processings in the control device 26 are summarized below. That is, they are described below with reference to a flow chart shown in Fig. 3.

[Step 1]

The signals x1, x2, x3 and x4 from detectors 21, 22 and 23 are captured.

[Step 2]

The relative position x1' of the trolley to the target position is calculated by

$$x1' = x1 - pset$$

The relative speed $x2'$ of the trolley to the set speed is calculated by

$$x2' = x2 - vset$$

[Step 3]

An acceleration/constant speed optimum control computation is done based on Numeric Expression (9) . As shown in Numeric Expression (10), moreover, the set speed is added to the results of computation.

$$u1 = [k1' \quad k2' \quad k3' \quad k4'] \begin{bmatrix} x1' \\ x2' \\ x3 \\ x4 \end{bmatrix} \text{-----(9)}$$

$$u1' = u1 + vset \quad (10)$$

[Step 4]

Positioning optimum control computation is done based on Numeric Expression (11).

$$u2 = [k1 \quad k2 \quad k3 \quad k4] \begin{bmatrix} x1' \\ x2 \\ x3 \\ x4 \end{bmatrix} \text{-----(11)}$$

[Step 5]

It is determined whether the relative position of the trolley to the target position is greater than a certain set value.

[Step 6]

When the relative position of the trolley to the target position is greater than the certain set value, the result of acceleration/constant speed optimum control is made a trolley speed command. That is,

$$u = u1'$$

[Step 7]

When the relative position of the trolley to the target position is smaller than the certain set value, the result of positioning optimum control is made a trolley speed command. That is,

$$u = u2$$

As described above, the control device has two control gains, one for control taking up a trolley speed and a swing,

and one for control taking up a trolley position and a swing, as control amounts. By switching between these two type of parameters, the device - performs control. Thus, it can constitute a suspended load steadying control device capable of keeping the swing of a suspended load minimal while the trolley is traveling.

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Claims

1. A suspended load steadying control device comprising:

10 a trolley motion state amount detector for detecting the motion state amount of a trolley in a crane suspending a load by a rope member;
 a suspended load motion state amount detector for detecting the motion state amount of the load suspended by the trolley; and
 a control device for performing steadying control of the suspended load based on detection signals introduced
 15 from the respective detectors;
 said control device comprising:
 a speed following optimum control portion for driving the trolley with the amount of optimum operation based on an optimum gain adjusted to follow a certain set speed, thereby performing steadying control;
 a positioning optimum control portion for driving the trolley with the amount of optimum operation based on
 20 an optimum gain adjusted to position the trolley at a certain target position, thereby performing steadying control; and
 a run state-wise control selection portion for selecting the speed following optimum control portion or the positioning optimum control portion based on the run state amount of the trolley, to drive the trolley.

25 2. The suspended load steadying control device of claim 1, wherein

the trolley motion state amount detector comprises a trolley displacement detector for detecting a trolley position, and a trolley speed detector for detecting a trolley speed,
 the suspended load motion state amount detector is a swing motion detector for detecting the swing displacement and swing speed of the suspended load, and
 30 when the relative position of the trolley to the target position is larger than a set value, the run state-wise control selection portion selects the speed following optimum control portion to drive the trolley, and when the relative position of the trolley to the target position is smaller than the set value, the run state-wise control selection portion selects the positioning optimum control portion to drive the trolley.

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Fig.1

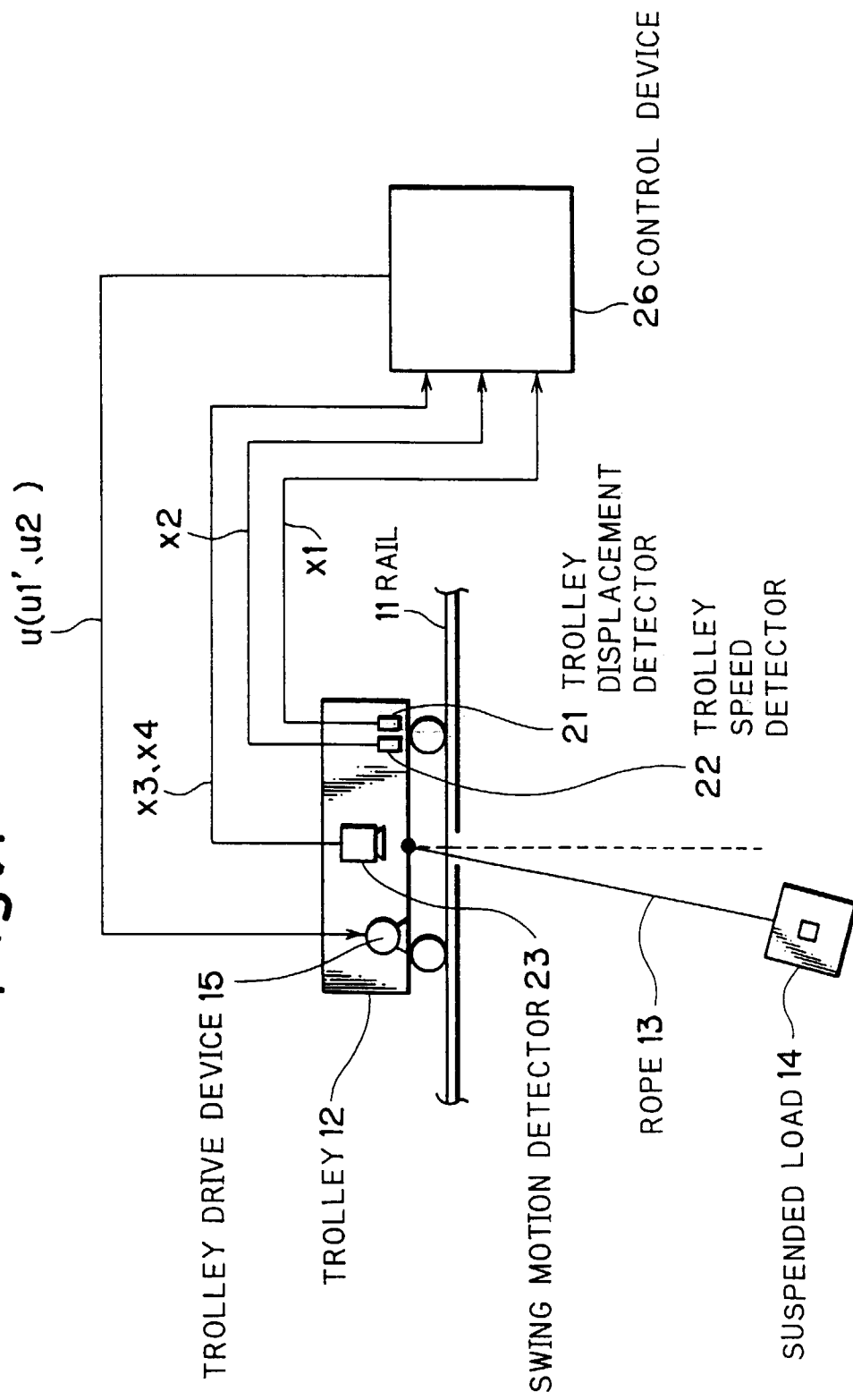


Fig.2

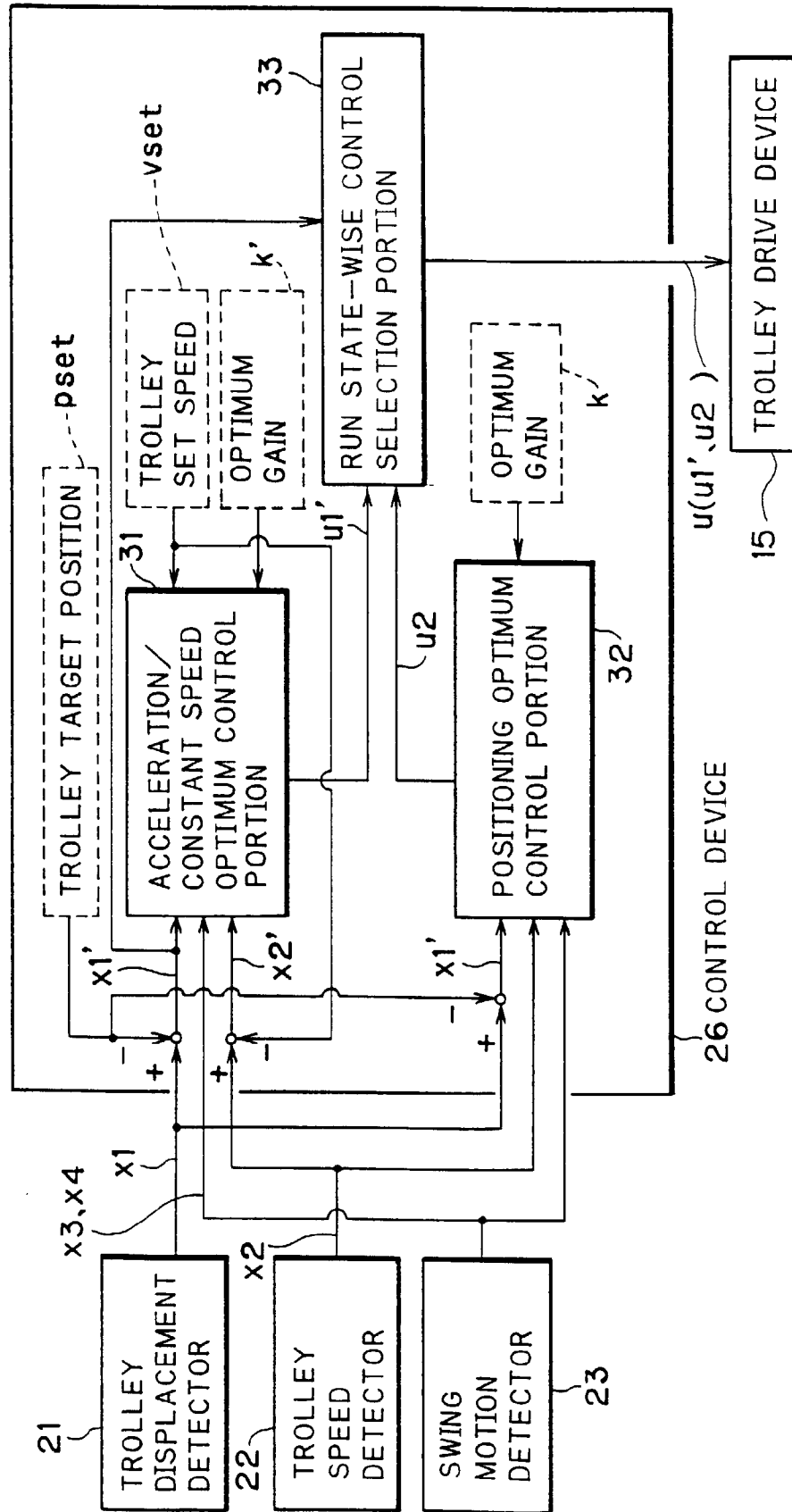


Fig.3

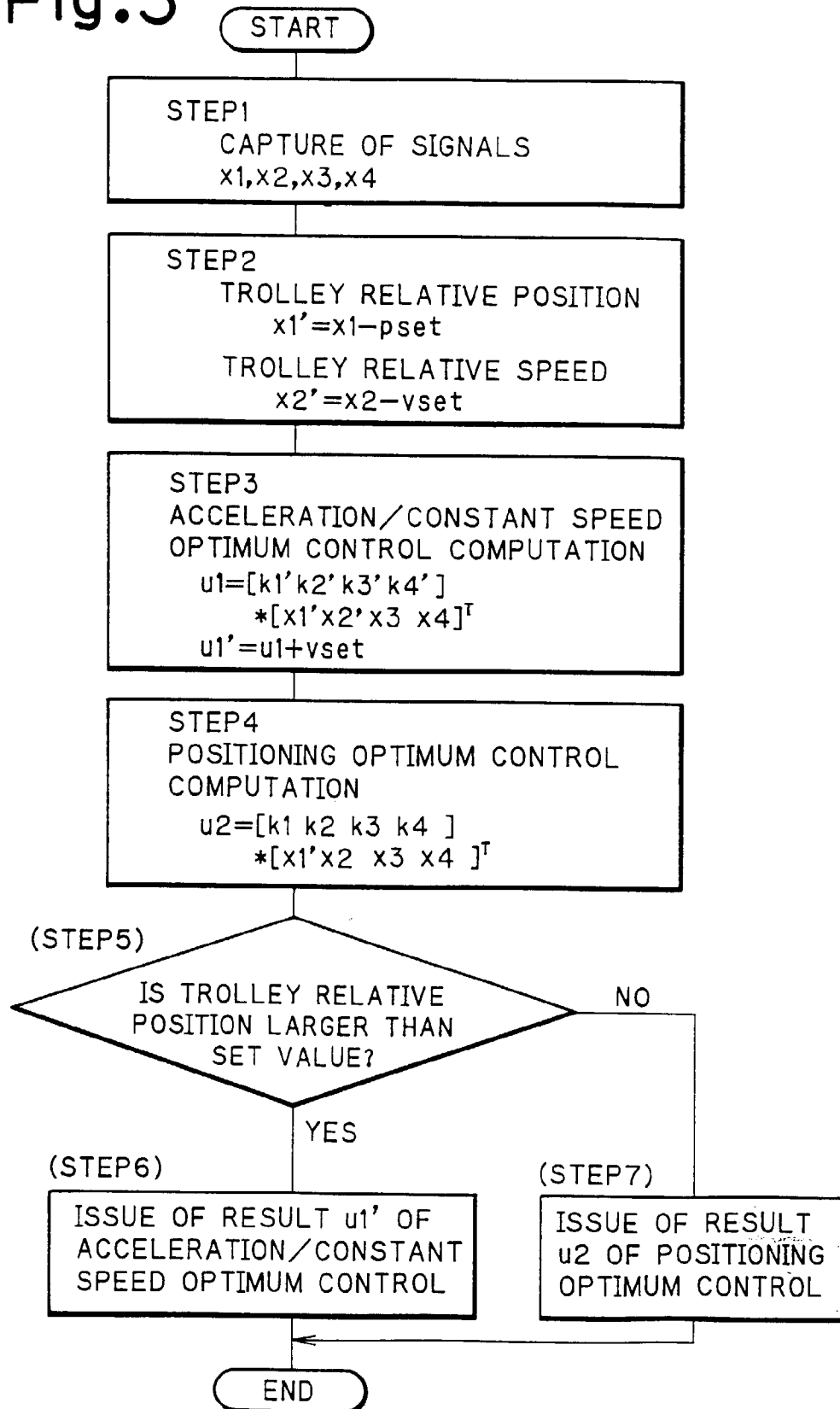


Fig.4

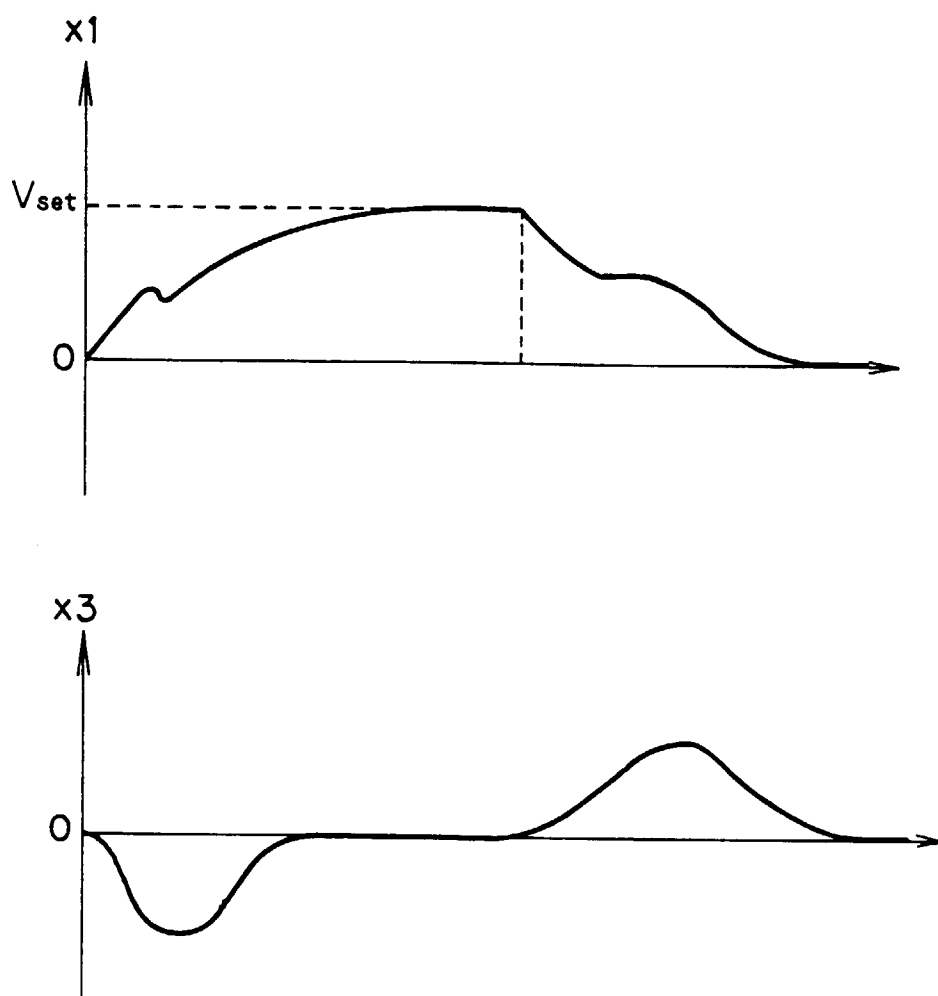


Fig.5

Prior Art

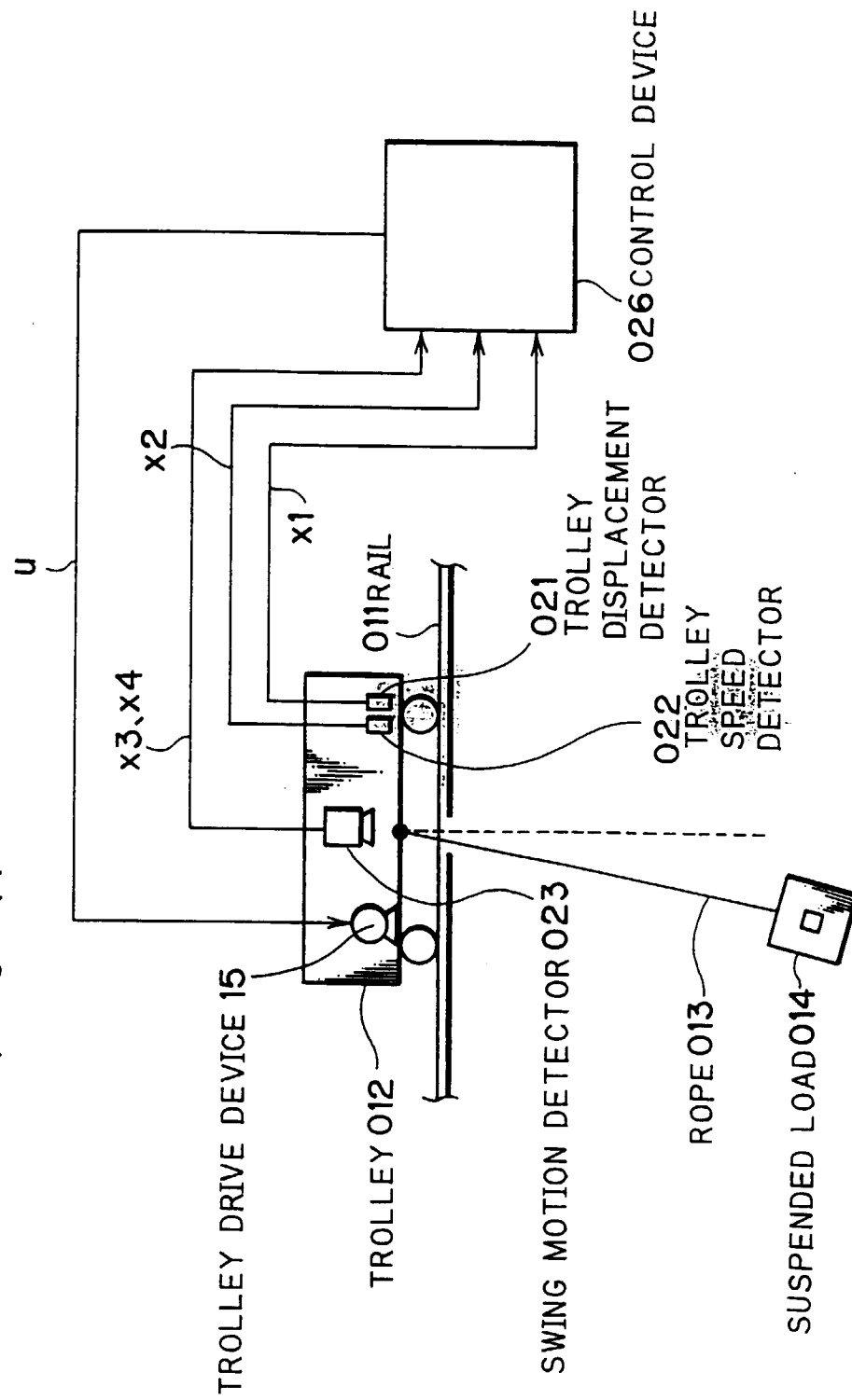


Fig.6
Prior Art

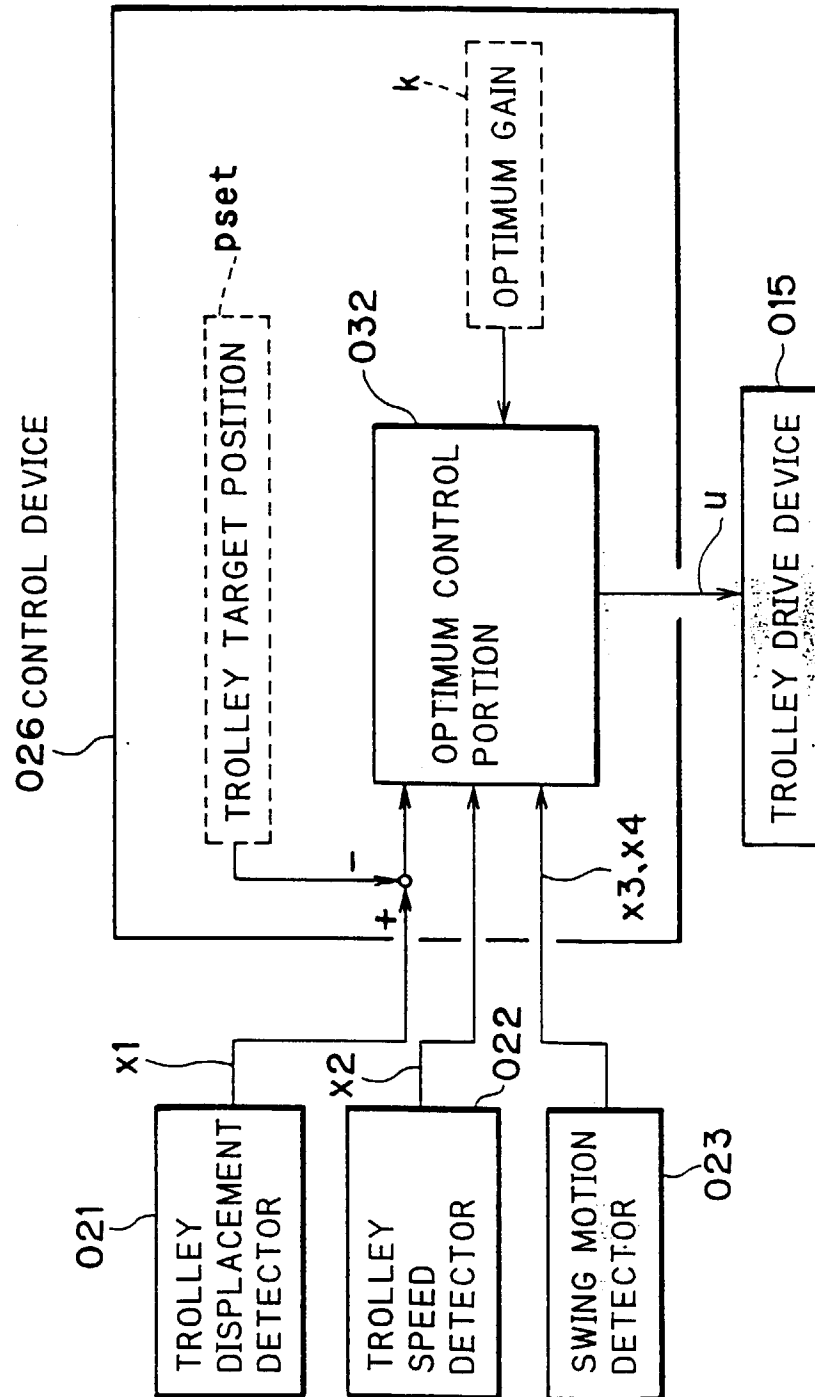


Fig.7

Prior Art

