United States Patent [19]

Yamagishi

[11] **3,921,818**

[45] **Nov. 25, 1975**

[54] **CRANE SUSPENSION CONTROL APPARATUS**

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[73] Assignee: **Tokyo Shibaura Denki Kabushiki Kaisha**, Japan

[22] Filed: **Mar. 28, 1974**

[21] Appl. No.: **455,906**

[30] **Foreign Application Priority Data**

Apr. 2, 1973 Japan 48-37665

[52] **U.S. Cl.** .... **212/132**; 212/39 R; 212/86; 318/384; 340/267 C

[51] **Int. Cl.**^{2} **B66C 19/00**

[58] **Field of Search** .... 318/384; 212/39 R, 132, 212/39 MS, 86; 340/267 C, 282, 197, 272

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Primary Examiner—Robert J. Spar
Assistant Examiner—R. B. Johnson
Attorney, Agent, or Firm—Stevens, Davis, Miller & Mosher

[57] **ABSTRACT**

A system for controlling a suspension type crane which moves transversely while suspending a load by a rope. The crane is accelerated at least two times to a predetermined maximum speed during an acceleration period, the swing of the rope is minimized when a predetermined maximum speed is reached, the crane is moved at the predetermined maximum speed for a predetermined interval, the crane is decelerated from the maximum speed at least two times during the deceleration period, and the crane is stopped when the swing of the rope is reduced to a minimum, and the areas of the acceleration and deceleration periods of the crane are made equal.

10 Claims, 20 Drawing Figures

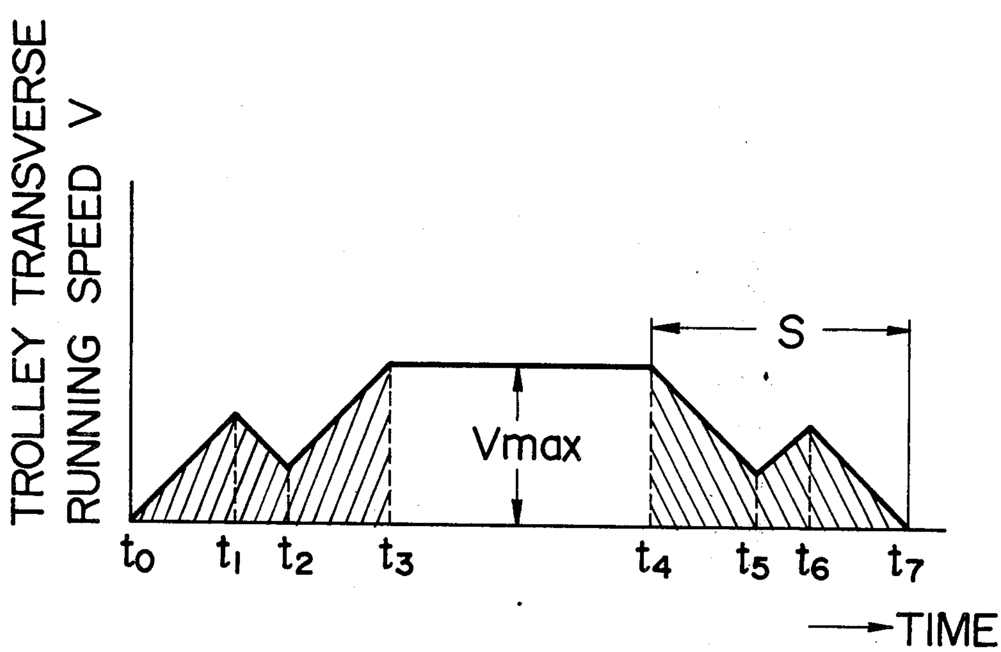


FIG. 1

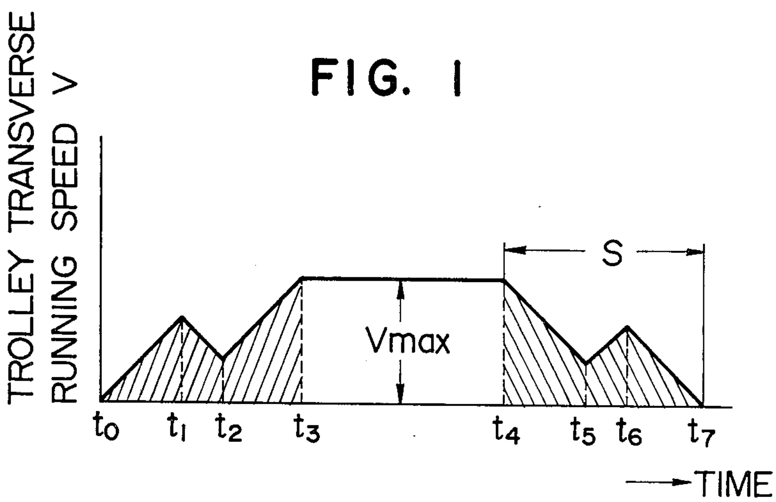

TROLLEY TRANSVERSE RUNNING SPEED V
S
Vmax
t_0 t_1 t_2 t_3 t_4 t_5 t_6 t_7
TIME

FIG. 2

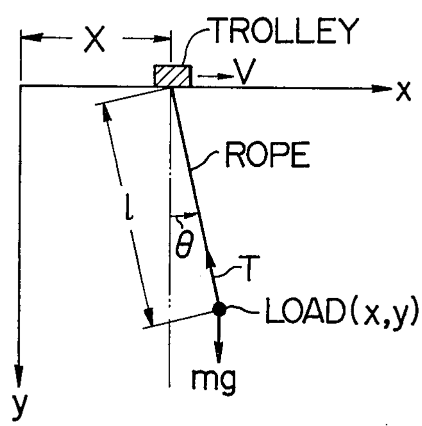

X
TROLLEY
V
x
ROPE
l
θ
T
LOAD(x,y)
mg
y

FIG. 3

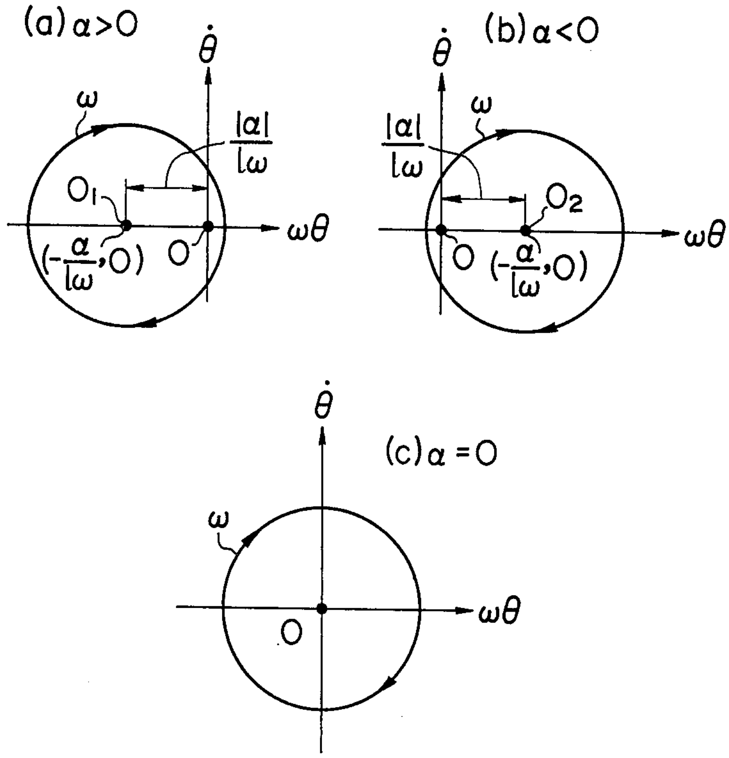

(a) α>0
θ̇
ω
|α|/lω
O1
(-α/lω, O)
O
ωθ
(b) α<0
θ̇
ω
|α|/lω
O2
O
(-α/lω, O)
ωθ
θ̇
(c) α = 0
ω
O
ωθ

FIG. 4

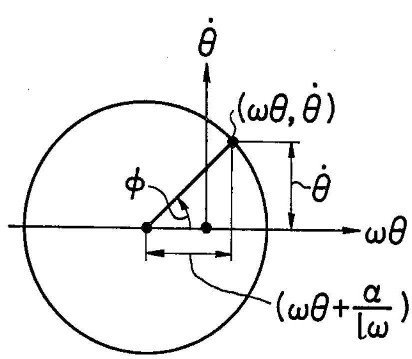

θ̇
(ωθ, θ̇)
φ
~θ̇
ωθ
(ωθ+α/lω)

FIG. 5

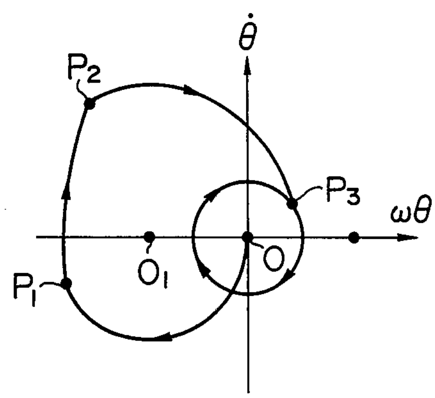


FIG. 6

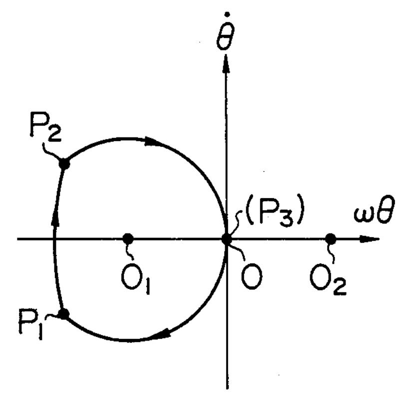


FIG. 7

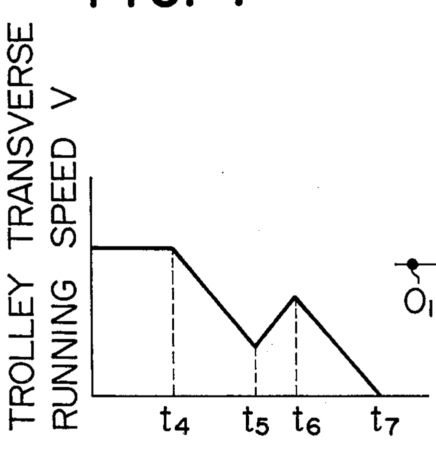


FIG. 8

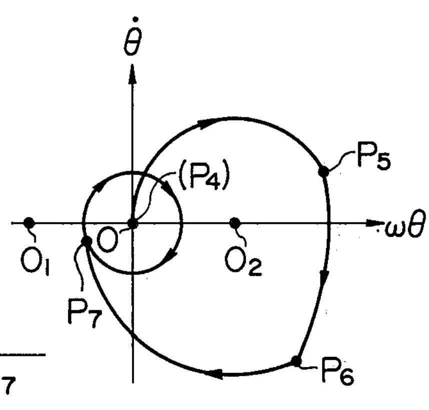


FIG. 9

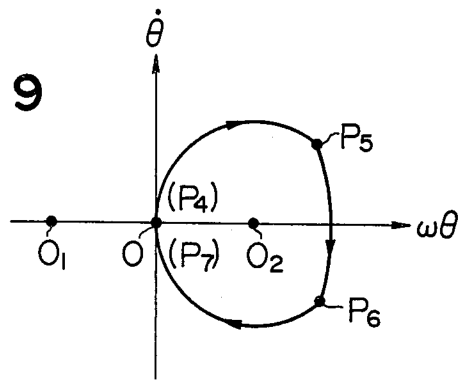


FIG. 10

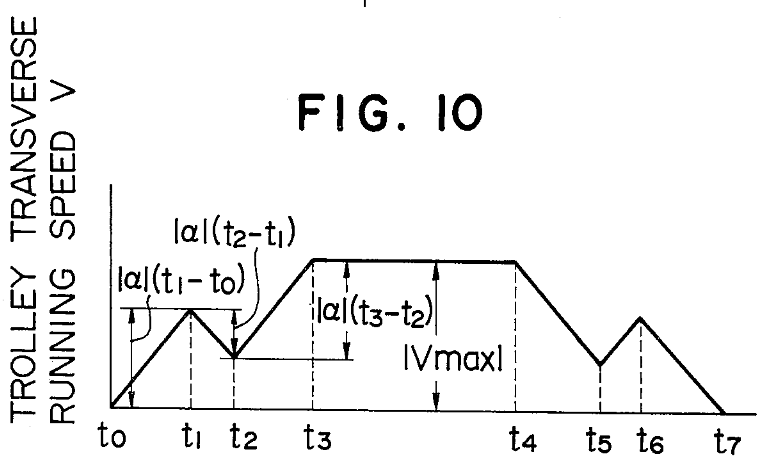


FIG. 11

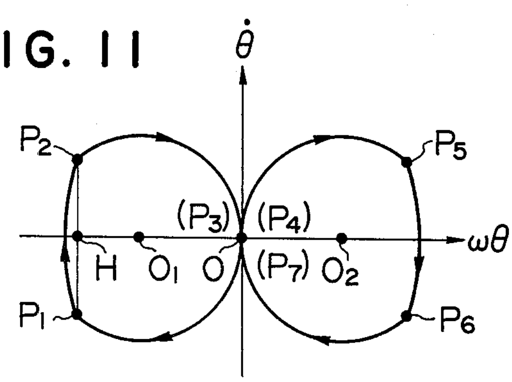


FIG. 12

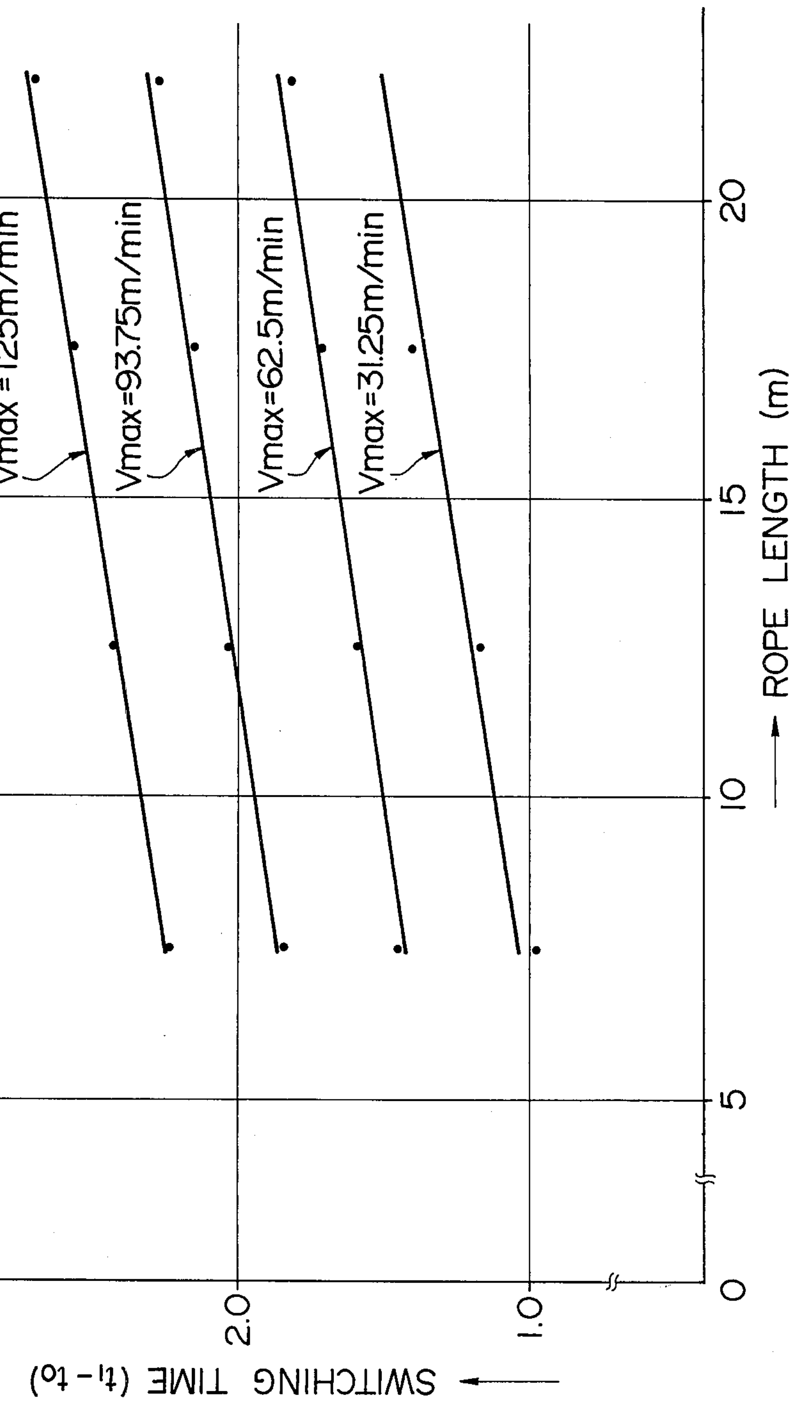

Vmax = 125m/min
Vmax=93.75m/min
Vmax=62.5m/min
Vmax=31.25m/min
2.0
1.0
0
5
10
15
20
→ ROPE LENGTH (m)
← SWITCHING TIME (t1 – t0)

FIG. 13

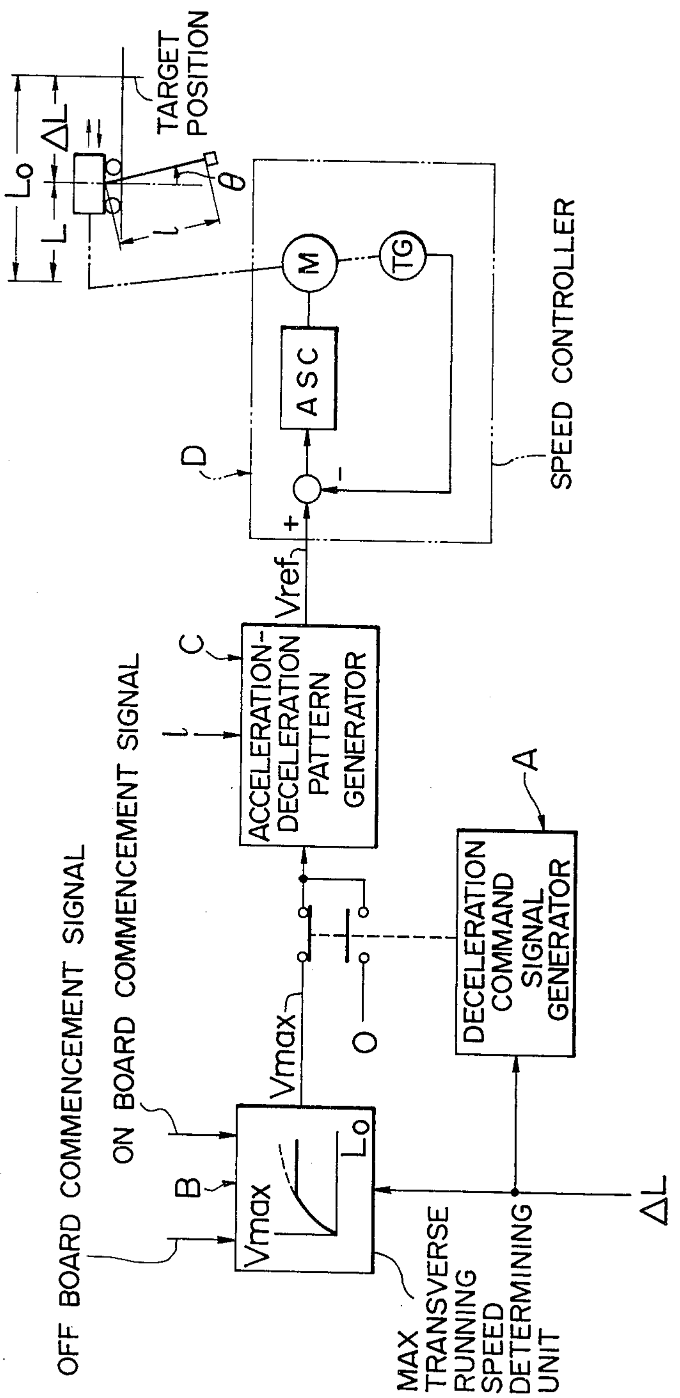
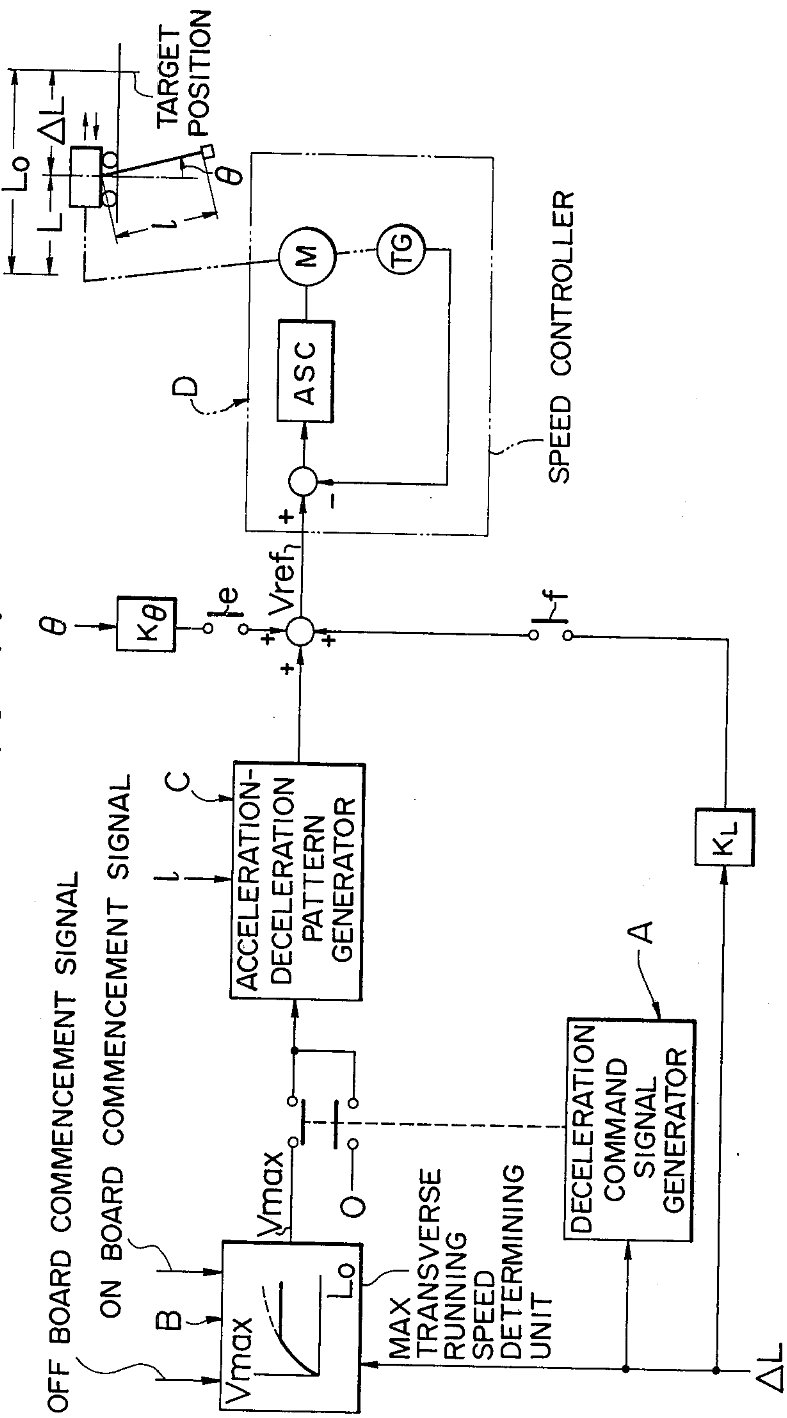
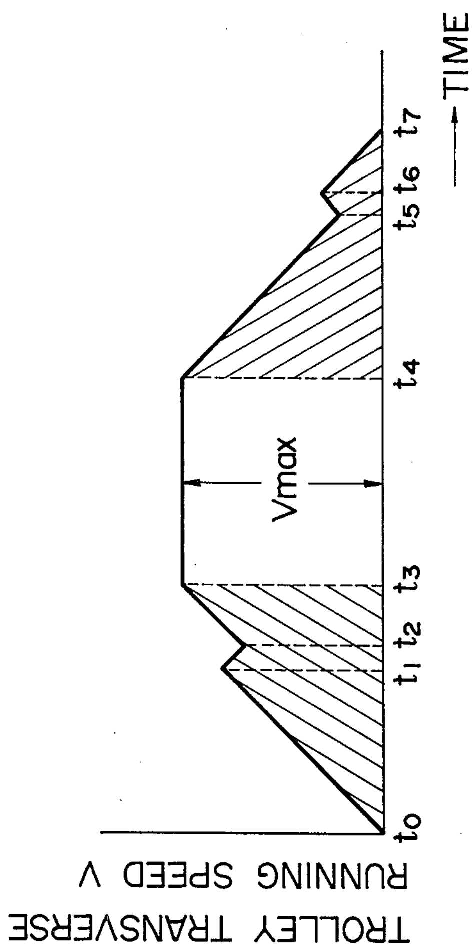

TARGET POSITION
Lo
ΔL
L
l
θ
M
TG
ASC
D
SPEED CONTROLLER
+
-
Vref
C
ACCELERATION-DECELERATION PATTERN GENERATOR
l
OFF BOARD COMMENCEMENT SIGNAL
ON BOARD COMMENCEMENT SIGNAL
B
Vmax
Lo
Vmax
O
DECELERATION COMMAND SIGNAL GENERATOR
A
MAX TRANSVERSE RUNNING SPEED DETERMINING UNIT
ΔL

FIG. 14



TARGET POSITION
Lo
L
ΔL
l
θ
D
M
TG
ASC
SPEED CONTROLLER
θ
Kθ
e
Vref
f
C
ACCELERATION-DECELERATION PATTERN GENERATOR
OFF BOARD COMMENCEMENT SIGNAL
ON BOARD COMMENCEMENT SIGNAL
B
Vmax
Vmax
Lo
O
MAX TRANSVERSE RUNNING SPEED DETERMINING UNIT
A
DECELERATION COMMAND SIGNAL GENERATOR
KL
ΔL

FIG. 15


TROLLEY TRANSVERSE RUNNING SPEED V
Vmax
t_0 t_1 t_2 t_3 t_4 t_5 t_6 t_7
→TIME

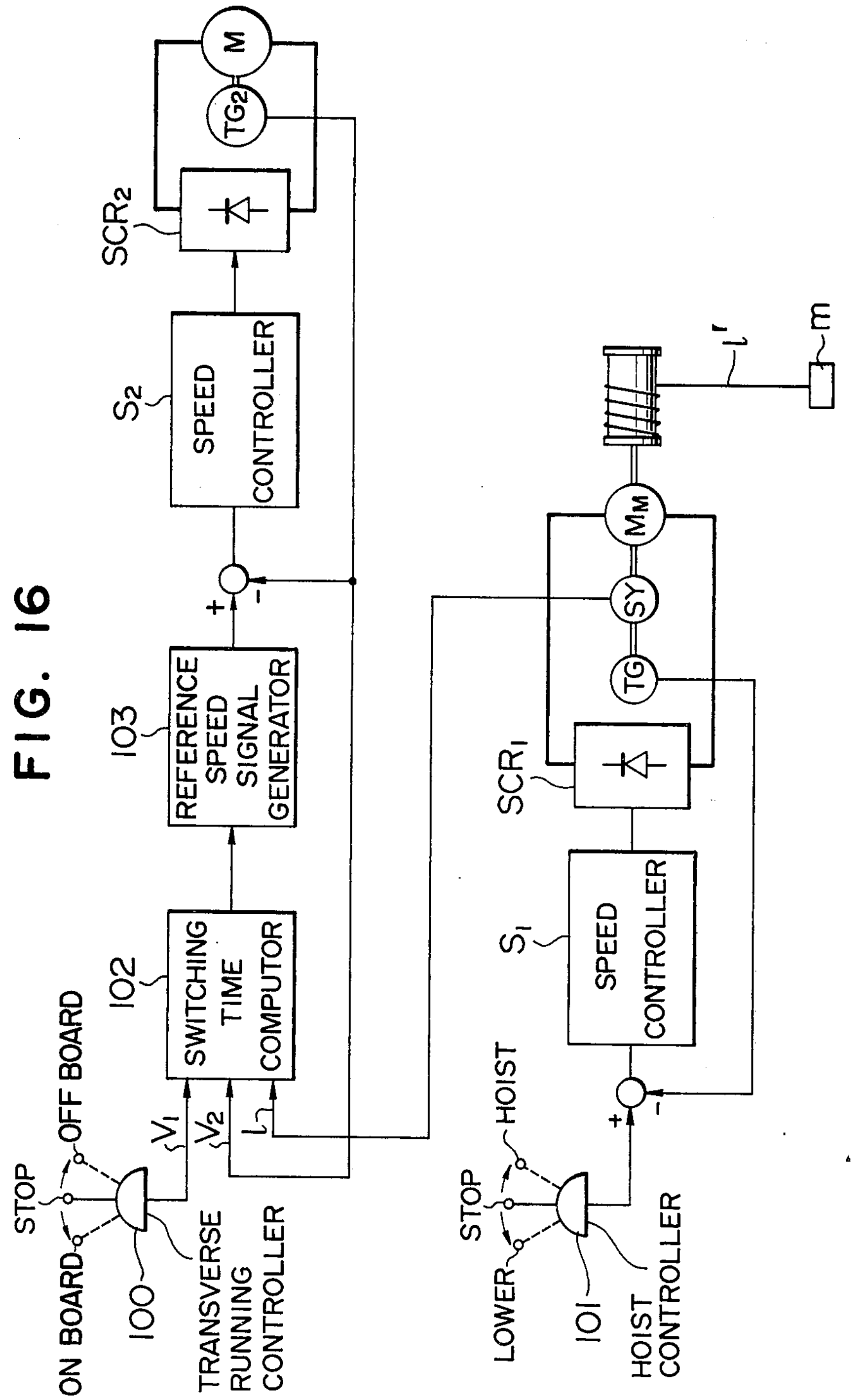

ON BOARD
STOP
OFF BOARD
100
TRANSVERSE RUNNING CONTROLLER
V_1
V_2
l
102
SWITCHING TIME COMPUTOR
103
REFERENCE SPEED SIGNAL GENERATOR
+
-
S_2
SPEED CONTROLLER
SCR_2
TG_2
M
LOWER
STOP
HOIST
101
HOIST CONTROLLER
+
-
S_1
SPEED CONTROLLER
SCR_1
TG
SY
M_M
l'
m

FIG. 16

FIG. 17

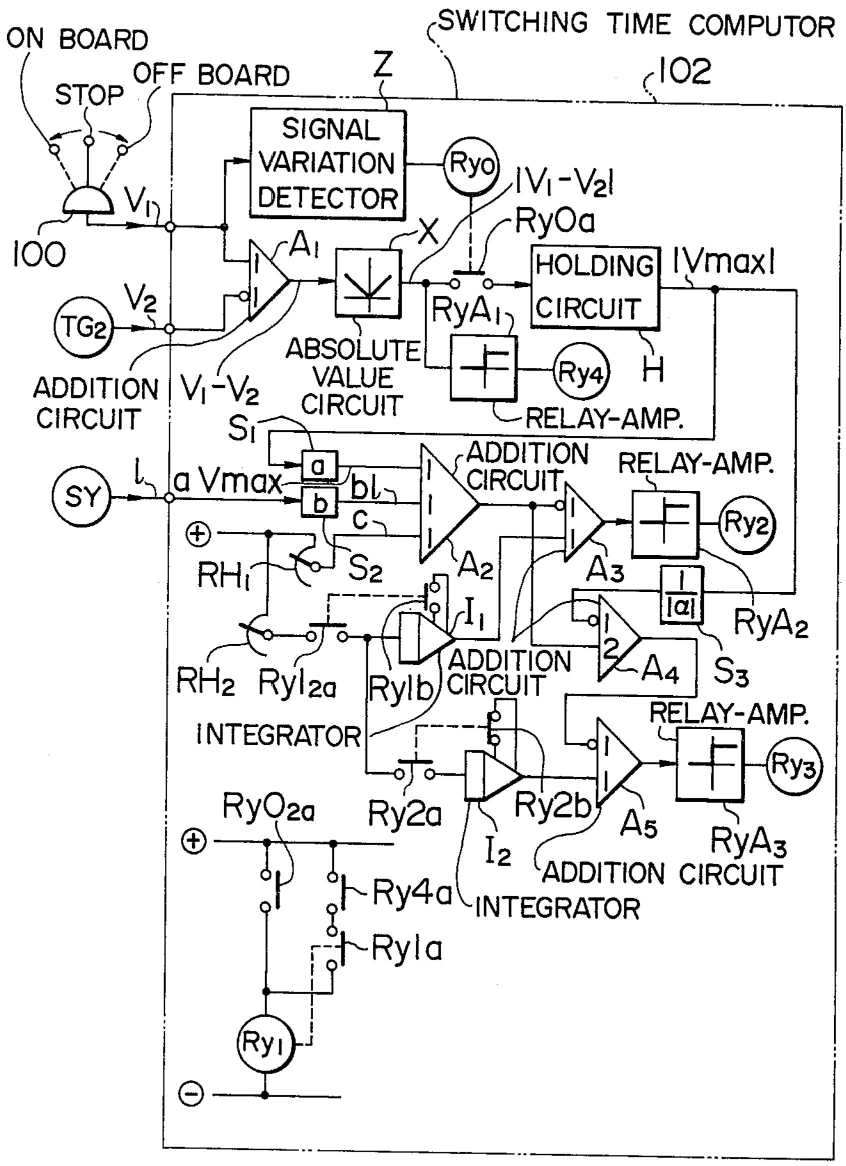

SWITCHING TIME COMPUTOR
102
ON BOARD
STOP
OFF BOARD
Z
SIGNAL VARIATION DETECTOR
Ryo
|V1-V2|
RyOa
X
A1
HOLDING CIRCUIT
|Vmax|
100
V1
V2
TG2
RyA1
H
Ry4
ABSOLUTE VALUE CIRCUIT
ADDITION CIRCUIT
V1-V2
RELAY-AMP.
S1
ADDITION CIRCUIT
RELAY-AMP.
SY
l
a Vmax
a
b
bl
c
A2
A3
Ry2
S2
RH1
I1
1/|a|
RyA2
RH2
Ryl2a
Rylb
ADDITION CIRCUIT
A4
S3
INTEGRATOR
RELAY-AMP.
Ry3
RyO2a
Ry2a
Ry2b
A5
RyA3
I2
ADDITION CIRCUIT
Ry4a
INTEGRATOR
Ryla
Ry1

FIG. 18

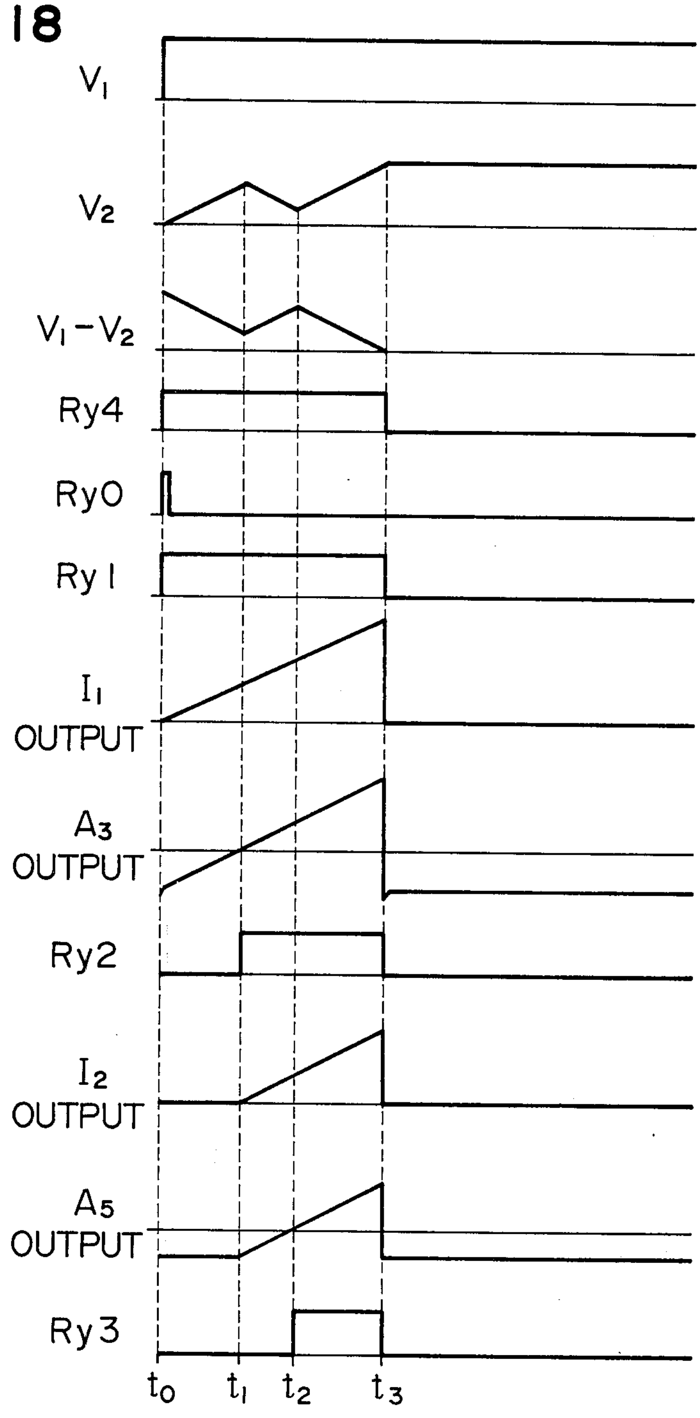

V1
V2
V1-V2
Ry4
Ry0
Ry1
I1 OUTPUT
A3 OUTPUT
Ry2
I2 OUTPUT
A5 OUTPUT
Ry3
t0
t1
t2
t3

FIG. 19

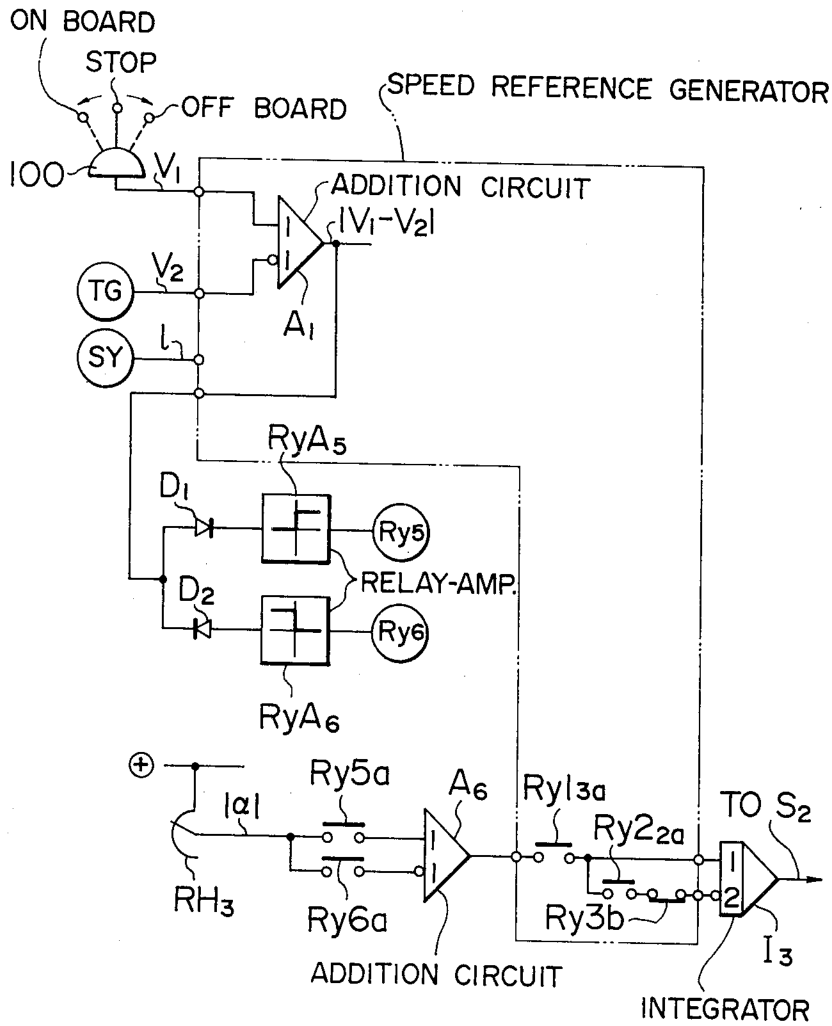
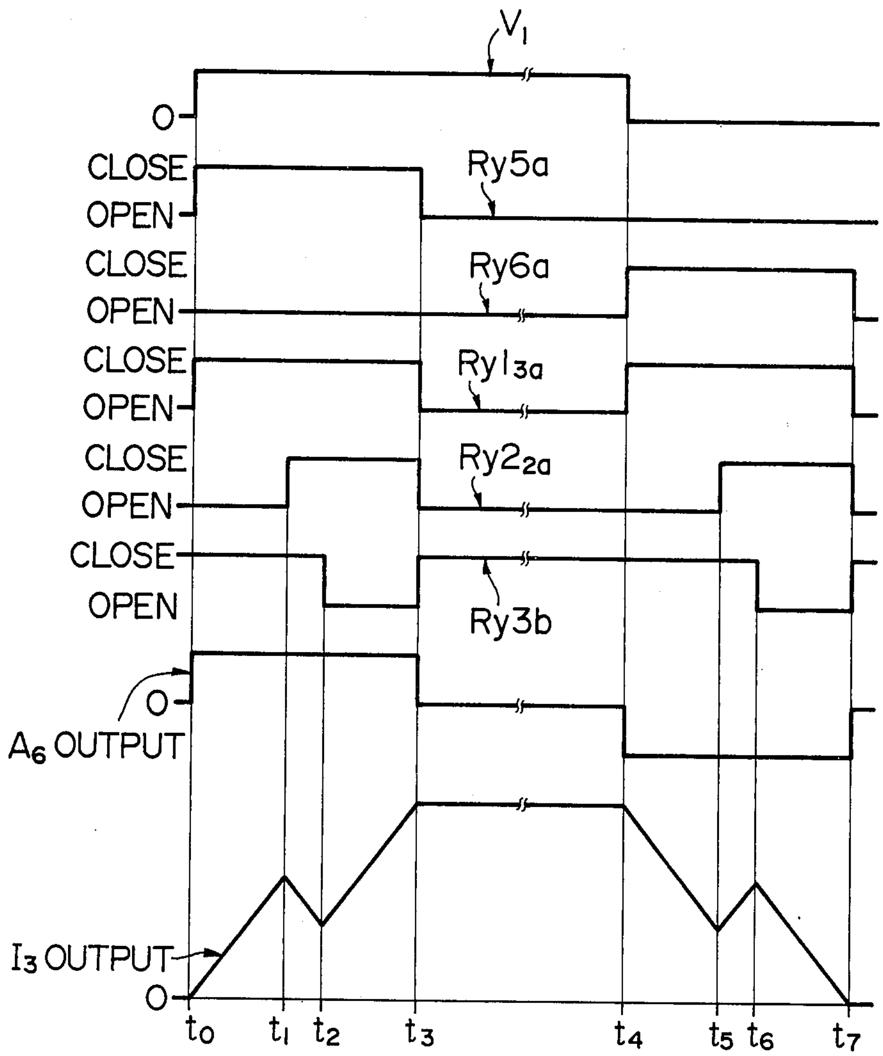

ON BOARD
STOP
OFF BOARD
SPEED REFERENCE GENERATOR
100
V1
ADDITION CIRCUIT
|V1-V2|
TG
V2
A1
SY
l
RyA5
D1
Ry5
RELAY-AMP.
D2
Ry6
RyA6
|α|
Ry5a
A6
Ry13a
Ry22a
TO S2
RH3
Ry6a
Ry3b
I3
ADDITION CIRCUIT
INTEGRATOR

FIG. 20


V1
O
CLOSE
OPEN
Ry5a
CLOSE
OPEN
Ry6a
CLOSE
OPEN
Ry13a
CLOSE
OPEN
Ry22a
CLOSE
OPEN
Ry3b
O
A6 OUTPUT
I3 OUTPUT
O
t0
t1
t2
t3
t4
t5
t6
t7

CRANE SUSPENSION CONTROL APPARATUS

BACKGROUND OF THE INVENTION

This invention relates to a method and system for controlling the positioning of a suspension type crane and more particularly to an improved method and system for suppressing swinging motions of a suspension rope of a trolley of the crane and for stopping the trolley at a correct target position when the swing of the rope is reduced to zero or substantially to zero.

When a suspension type crane is accelerated or decelerated during its transverse running, the rope suspending a load undergoes a pendulum motion. Such pendulum motion or swinging motion can be suppressed by the operation of the operator of the crane. Thus, when such swinging motion occurs the operator operates the controller of the crane for adjusting the transverse running speed to suppress the swinging motion. However, such adjustment cannot be made other than by a skilled crane operator and in most cases the adjustment of the transverse running speed becomes excessive or insufficient whereby a long time is required until the swinging motion is perfectly suppressed thus decreasing the cargo efficiency.

To obviate this difficulty, there has been proposed a method wherein the swinging angle θ of the rope and the angular velocity $\dot{\theta}$ of the swinging motion are detected and signals corresponding to angle θ and angular velocity $\dot{\theta}$ are negatively fed back to a transverse speed controller through a feedback circuit having a suitable gain for attenuating the swinging motion of the rope. With such a feedback system, if the gain of the feedback circuit were decreased for sufficiently suppressing the swinging motion the average transverse running speed would be decreased. Accordingly, a compromise method has been proposed in which an insensitive zone is provided for the feedback circuit for preventing the cargo efficiency from decreasing at the sacrifice of the accuracy of the swing suppression. Accordingly, such method is not satisfactory for such an application as a container crane which requires an extremely accurate swing suppression for the purpose of precisely lowering the load at a predetermined position.

In order to have a better understanding of this invention, the problem involved in the control system for effecting suppression of the swinging motion in a shortest time will be analyzed hereunder.

In a diagram shown in FIG. 2, let m represents the mass of a load, T the tension of a suspension rope, g the acceleration due to gravity. Under a balanced condition of the horizontal component and the vertical component of the force acting upon the load, the following equations of motion hold:

$$m \frac{d^2x}{dt^2} = -T \sin\theta \qquad 1.$$

and

$$m \frac{d^2y}{dt^2} = mg - T\cos\theta \qquad 2.$$

There are the following relations among x, y, l (length of the rope), θ (angle of swing) and X (distance between the origin and the trolley)

$$x = X + l \sin\theta \qquad -3.$$
$$y = l \cos\theta \qquad -4.$$

By differentiating both sides of equations 3 and 4 with respect to time t, we obtain

$$\frac{dx}{dt} = \frac{dx}{dt} + \frac{dl}{dt}\sin\theta + l\frac{d\theta}{dt}\cos\theta \qquad 5.$$

$$\frac{dy}{dt} = \frac{dl}{dt}\cos\theta - l\frac{d\theta}{dt}\sin\theta \qquad 6.$$

By additionally differentiating both sides of equations 5 and 6 with respect to time, we obtain

$$\frac{d^2x}{dt} = \frac{d^2X}{dt^2} + \frac{d^2l}{dt}\sin\theta + \frac{dl}{dt}\frac{d\theta}{dt}\cos\theta + \frac{dl}{dt}\frac{d\theta}{dt}\cos\theta + l\frac{d^2\theta}{dt}\cos\theta - l\left(\frac{d\theta}{dt}\right)^2\sin\theta$$
$$= \frac{d^2X}{dt^2} + \left\{\frac{d^2l}{dt^2} - l\left(\frac{d\theta}{dt}\right)^2\right\}\sin\theta + \left(2\frac{dl}{dt}\frac{d\theta}{dt} + l\frac{d^2\theta}{dt^2}\right)\cos\theta \qquad 7.$$

$$\frac{d^2y}{dt^2} = \frac{d^2l}{dt^2}\cos\theta - \frac{dl}{dt}\frac{d\theta}{dt}\sin\theta - \left\{\frac{dl}{dt}\frac{d\theta}{dt}\sin\theta + l\frac{d\theta}{dt}\sin\theta + l\left(\frac{d\theta}{dt}\right)\cos\theta\right\}$$
$$= \left\{\frac{d^2l}{dt^2} - l\left(\frac{d\theta}{dt}\right)^2\right\}\cos\theta - \left\{2\frac{dl}{dt}\frac{d\theta}{dt} + l\frac{d^2\theta}{dt^2}\right\}\sin\theta \qquad 8.$$

Substituting equations 7 and 8 for the lefthand sides of equations 1 and 2, respectively,

$$m\frac{d^2x}{dt^2} + m\left\{\frac{d^2l}{dt^2} - l\left(\frac{d\theta}{dt}\right)^2\right\}\sin\theta + m\left\{2\frac{dl}{dt}\frac{d\theta}{dt} + l\frac{d^2\theta}{dt^2}\right\}\cos\theta = -T\sin\theta \qquad 9.$$

$$m\left\{\frac{d^2l}{dt^2} - l\left(\frac{d\theta}{dt}\right)^2\right\}\cos\theta - m\left\{2\frac{dl}{dt}\frac{d\theta}{dt} + l\frac{d^2\theta}{dt^2}\right\}\sin\theta = mg - T\cos\theta \qquad 10.$$

When an equation

$$\text{equation } 9 \times \cos\theta - \text{equation } 10 \times \sin\theta$$

is operated, the second term in the lefthand side of equation 9 and the first term in the lefthand side of equation 10 cancel with each other, and the righthand side of equation 9 and the second term in the righthand side of equation 10 also cancel with each other, thus

$$m\frac{d^2x}{dt^2}\cos\theta + m\left\{2\frac{dl}{dt}\frac{d\theta}{dt} + l\frac{d^2\theta}{dt^2}\right\}(\sin^2\theta + \cos^2\theta) = -mg\sin\theta \qquad 11.$$

By dividing the both sides of equation 11 by m and by sustituting a relation $\sin^2\theta + \cos^2\theta = 1$

$$\frac{d^2t}{dt^2}\cos\theta + 2\frac{dl}{dt}\frac{d\theta}{dt} + l\frac{d^2\theta}{dt} = g\sin\theta \qquad 12.$$

By putting

$$\frac{dx}{dt} = V,$$

we obtain

$$\frac{d^2x}{dt^2} = \frac{dV}{dt}$$

Where θ is small, then $\cos\theta \doteqdot 1$ and $\sin\theta \doteqdot \theta$, so that equation 12 can be rewritten as follows

$$\frac{dV}{dt} + 2\frac{dl}{dt}\frac{d\theta}{dt} + l\frac{d^2\theta}{dt^2} = -g\theta \qquad 13.$$

Thus, equation 13 expresses the pendulum motion of the rope and the load.

If we assume that, the length **l** of the rope is constant, then

$$\frac{dl}{dt} = 0$$

and equation 13 can be rewritten as follows.

$$l\frac{d^2\theta}{dt} + g\theta = -\frac{dV}{dt} \qquad 14.$$

Since there is a relation:

$$\frac{d\theta^2}{dt^2} = \frac{d}{dt}\left(\frac{\theta}{dt}\right) = \frac{d\theta}{dt}\cdot\frac{d}{d\theta}\left(\frac{d\theta}{dt}\right)$$

by putting

$$\frac{dO}{dt}\cdot\frac{d}{d\theta}\left(\frac{d\theta}{dt}\right) = \dot\theta\frac{d\dot\theta}{dt}$$

and by substituting this relation in equation 14, we obtain

$$l\dot\theta\frac{d\dot\theta}{d\theta} + g\theta = -\frac{dV}{dt} \qquad 15.$$

By dividing the both sides of equation 15 by l and by putting

$$\frac{dv}{dt} = \alpha, \text{ and } \frac{g}{l} = \omega^2$$

the following relation can be obtained

$$\theta^2\frac{d\theta^2}{d\theta} + \omega^2\theta + \frac{d}{l} = 0 \qquad 16.$$

When the both sides of equation 16 are integrated with respect to θ, under an assumption that the acceleration α of the trolley is constant, the following equation will be obtained

$$\tfrac{1}{2}(\dot\theta)^2 + \tfrac{1}{2}\omega^2\theta^2 + \frac{\alpha}{l}\theta = Co \qquad 17.$$

where Co represents an integration constant.

By multiplying the both sides of equation 17 by 2,

$$(\theta)^2 + \left\{(\omega\theta)^2 + \alpha\frac{2}{l}\theta\right\} = 2Co \qquad 18.$$

By modifying the term in the bracket and by substituting the result of the following equation 19 into equation 18, we obtain equation 20.

$$(\omega\theta)^2 + 2\frac{\alpha}{l}\theta = \left\{(\omega\theta)^2 + 2(\omega\theta)\frac{\alpha}{l\omega} + \left(\frac{\alpha}{l\omega}\right)^2\right\} - \left(\frac{\alpha}{l\omega}\right.$$

$$= \left(\omega\theta + \frac{\alpha}{l\omega}\right)^2 - \left(\frac{\alpha}{l\omega}\right)^2 \qquad 19.$$

$$(\theta)^2 + \left(\omega\theta + \frac{\alpha}{l\omega}\right)^2 = C^2 \qquad 20.$$

where $C^2 = 2Co + \left(\frac{\alpha}{l\omega}\right)^2$

When the length **l** of the rope is constant, the relationship between $\omega\theta$ and $\dot\theta$ or the phase plane locus corresponds to a circular motion rotating in the clockwise direction at a constant angular velocity ω on a circle having a center at

$$\left(-\frac{\alpha}{l\omega}, 0\right),$$

as shown in **FIG. 3.**

The speed of the motion around the circle can be obtained as follows. As shown in **FIG. 4,** since

$$\tan\phi = \frac{\dot\theta}{\left(\omega\theta + \frac{\alpha}{l\omega}\right)} \qquad 21.$$

$$\phi = \tan^{-1}\frac{\dot\theta}{\left(\omega\theta + \frac{\alpha}{l\omega}\right)} = \tan^{-1}Z \qquad 22.$$

where

$$Z = \frac{\dot\theta}{\omega\theta + \frac{\alpha}{l\omega}}$$

Accordingly, the angular speed of the circular motion of a point $(\omega\theta, \theta)$ can be expressed as follows

$$\frac{d\phi}{dt} = \frac{dZ}{dt} \cdot \frac{d}{dZ}(\tan^{-1} Z)$$

$$= \frac{\ddot{\theta}\,(\omega\,\theta + \frac{\alpha\omega}{1\omega})\,\omega\,(\dot{\theta})^2}{(\omega\,\theta + \frac{\alpha}{1\omega})} \times \frac{-1}{1 + \left(\frac{\dot{\theta}}{\omega\,\theta + \frac{\alpha}{1\omega}}\right)^2}$$

$$= \frac{\ddot{\theta}\,(\omega\,\theta + \frac{\alpha}{1}) - \omega\,(\dot{\theta})^2}{(\omega\,\theta + \frac{\alpha}{1\omega})^2 + (\dot{\theta})^2} \qquad 23.$$

where

$$\ddot{\theta} = \frac{d\dot{\theta}}{dt}$$

From equation 14

$$\ddot{\theta} = -\left(\frac{g}{1}\theta + \frac{\alpha}{1}\right) = -\left(\omega^2\theta + \frac{\alpha}{1}\right)$$

$$= -\omega\left(\omega\,\theta + \frac{\alpha}{1\omega}\right) \qquad 24.$$

By substituting equation 24 into equation 23 the following equation can be derived

$$\frac{d\phi}{dt} = \frac{-\omega\,(\omega\theta + \frac{\alpha}{1\omega})\,(\omega\theta + \frac{\alpha}{1\omega}) - \omega(\dot{\theta})^2}{(\omega\theta + \frac{\alpha}{1\omega})^2 + (\dot{\theta})^2} = -\omega$$

This equation shows that the point $(\omega\theta, \dot{\theta})$ rotates on a circle in the clockwise direction at a constant angular velocity ω, as has been pointed out hereinabove.

It can be readily understood that, during acceleration since $\alpha > 0$, the center of the circle lies on the negative side of axis $\omega\ \theta$, whereas during decelration since $\alpha < 0$, the center of the circle lies on the positive side, as shown by FIGS. 3*a* and 3*b*. Where the trolley is running transversely at a constant speed, $\alpha = 0$ so that the center of the circle coincides with the origin **0** as shown in FIG. 3*c*. Further, the radius of the circle is determined by the initial conditions.

Assume now that the trolley is started from standstill at a constant acceleration, decelerated at a constant deceleration during an interval $t_1 - t_2$ and thereafter again accelerated at a constant acceleration during an interval $t_2 - t_3$ until a maximum speed is reached, as shown in FIG. **1**. Under these conditions, the relationship between the swing angle θ and the angular velocity $\dot{\theta}$ of the swinging motion will now be considered with reference to the phase phane locus described above.

Since the initial conditions are: $t = t_o$, $\theta = 0$ and $\dot{\theta} = 0$, the phase plane locus starts from the origin **0** as shown in FIG. **5** so that the initial radius of the circle is equal to $\overline{O,O}$. When the position of a state point $(\omega\theta, \dot{\theta})$ at $t = t_1$ is denoted by P_1, the time required for the point P_1 to move from O to P_1 is equal to $(t_1 - t_o)$, and since the angular velocity of the circular motion of the state joint P_1 about the center O_1 is expressed by ω, the following relation holds

$$\angle OO_1P_1 = \omega\,(t_1 - t_o) \qquad 26.$$

During a period t expressed by $t_1 \leqslant t \leqslant t_2$, $\alpha < 0$ so that the phase plane locus becomes a circle having a center at θ_2. At an instant $t = t_1$, arc $\widehat{P_1P_2}$ intersects arc $\widehat{UP_1}$ at point P_1 so that the radius of the latter circle will be $\overline{O_2P_1}$. By denoting the position of a state point $(\omega\theta, \dot{\theta})$ at $t = t_2$ by P_2, the time required for the state point to move from point P_1 to point P_2 will be $(t_2 - t_1)$ and since the angular velocity of the circular motion about the center O_2 is ω, the following relation holds,

$$P_1O_2P_2 = \omega\,(t_2 - t_1) \qquad 27.$$

During an interval expressed by a relation $t_2 \leqq t \leqq t_3$, since $\alpha > 0$, the phase plane locus again assumes the circle with its center at O_1. At $t = t_2$, since arc $\widehat{P_2P_3}$ intersects arc $\widehat{P_1P_2}$ at point P_2, the radius of the circle having a center at point O_1 is equal to $\overline{O_1P_2}$. Further, since the time required for the state point to move from point P_2 to state point P_3 is equal to $(t_3 - t_2)$ and the angular velocity of the circular motion about center O_1 is ω, the following relation holds

$$\angle P_2O_1P_3 = \omega\,(t_3 - t_2) \qquad 28.$$

During an interval wherein $t_2 \geqslant t_3$, as $\alpha = 0$, the phase surface locus takes the form of a circle having its center at the origin and a radius $\overline{OP_3}$.

From the foregoing description, it will be clear that the phase surface locus varies when the time instants t_1 and t_2, FIG. **1**, at which the acceleration is switched to deceleration or vice versa are varied.

For example, when state point P_3 is made to coincide with the origin O as shown in FIG. **6** by a suitable selection of acceleration-deceleration switching points t_1 and t_2, when the state point P_3 is reached or when the trolley attains the maximum running speed, both swing angle θ and angular velocity $\dot{\theta}$ of the swinging motion become zero so that it will be clear that during the succeeding interval in which the trolley runs at a constant speed the swing angle of the rope is always maintained zero.

Let us now consider a case wherein the trolley running at the maximum speed is to be stopped. Consider now a speed pattern as shown in FIG. **7** wherein the deceleration of the trolley is commenced at time t_4, acceleration is commenced at time t_5 and thereafter deceleration is commenced again at time t_6. The phase plane locus in this case is shown in FIG. **8**. As has been pointed out hereinabove, as it is possible to make zero both the swing angle θ and the angular velocity of the swinging motion $\dot{\theta}$ during the interval in which the trolley is running at a constant speed, if the state point coincides with the origin at $t = t_4$, the phase plane locus shown in FIG. 8 would originate from the origin O.

Since $\alpha<0$ during an interval $t_4 \leq t \leq t_5$, the phase plane locus will become a circle having its center at point O_2 and a radius of $\overline{O_2O}$.

Further, since $\alpha>0$ during an interval $t_5 \leq t \leq t_6$, the phase plane locus will become a circle having its center at point O_1 and a radius of $\overline{O_1P_5}$.

During an interval $t_6 \leq t \leq t_7$ in which $\alpha<0$, the phase plane locus will again become the circle having its center at point O_2 and a radius $\overline{O_2P_6}$ as determined by the intersecting condition of the locus at state point P_6.

At a time $t = t_7$ the trolley stops and thereafter since $\alpha = 0$, the phase surface locus would be a circle having its center at the origin O and a radius of $\overline{OP_7}$.

In this manner, by the suitable selection of the acceleration-deceleration switching points t_5 and t_6 it is possible to make the phase plane locus as that shown in FIG. 9. At a time $t = t_7$ at which the trolley stops, since both the swing angle θ of the rope and the angular velocity $\dot{\theta}$ of the swinging motion are zero and since $\alpha = 0$ during the period $t \geq t_7$, the rope will be maintained in a condition in which its swing is zero.

For this reason, where the speed pattern from start to stop of the trolley is selected to be equal to that shown in FIG. 10 and where the switching points t_1, t_2-t_6 are determined such that a phase plane locus as shown in FIG. 11 can be provided, it is possible to make zero the swing of the rope both during the period $t_3 - t_4$ in which the trolley runs at a constant running speed and at time t_7 at which the trolley stops.

It will thus be clear that it would not be necessary to vary the speed pattern during the intervals $t_o - t_3$ and $t_4 - t_7$ in accordance with the transverse running distance or stroke of the trolley if the interval $t_3 - t_4$ in which the trolley runs at the constant speed were varied in accordance with the transverse stroke of the trolley when it is controlled by the speed pattern as shown in FIG. 10. The fact that the swing angle θ of the rope is kept at zero during the interval $t_3 - t_4$ of the constant speed running is advantageous from the standpoint of safeness of the cargo operation. The locus $P_4 - P_5 - P_6 - P_7$ shown in FIG. 11 can be obtained by tracing the locus $O - P_1 - P_2 - P_3$ in the opposite direction.

Consequently, following equations hold.

$$t_1 - t_o = t_7 - t_6 = t_3 - t_2 \qquad \text{-29.}$$

$$t_2 - t_1 = t_6 - t_5 \qquad \text{-30.}$$

$$t_3 - t_2 = t_5 - t_4 \qquad \text{-31.}$$

Let us now consider the acceleration-deceleration switching points which are so selected that the phase plane locus shown in FIG. 11 can be obtained.

From FIG. 10, the following equation holds

$$|\alpha|(t_1 - t_0) - |\alpha|(t_2 - t_1) + |\alpha|(t_3 - t_2) = V\max \qquad \text{-32.}$$

and from FIG. 11

$$\angle OO_1P_1 = \angle OO_1P_2 \qquad \text{-33.}$$

so that from equations 26 and 28 we obtain

$$t_1 - t_o = t_3 - t_2 \qquad \text{-34.}$$

With reference to an arc $\overset{\frown}{OP_1}$ shown in FIG. 11 since $\overline{OO_1} = \overline{O_1P_1}$

$$\overline{P_1H} = \overline{OO_1} \sin(\angle OO_1P_1) = \frac{|\alpha|}{l\omega} \sin\left\{\omega(t_1 - t_o)\right\} \qquad 35.$$

with reference to an arc P_1P_2 having a center at O_{21}

$$\overline{P_1H} = \overline{O_2H} \cdot \tan\left(\frac{\angle P_1O_2P_2}{2}\right) = \overline{O_2H} \cdot \tan\left\{\frac{\omega(t_2 - t_1)}{2}\right\} \qquad 36.$$

However

$$\begin{aligned}\overline{O_2H} &= \overline{O_2O} + \overline{OO_1} + \overline{O_1H} = +\overline{OO_1} + \overline{OO_1} + \overline{O_1H} \\ &= 2.\overline{OO_1} + \overline{O_1P_1}\cos(\angle P_1O_1H) \\ &= 2\frac{|\alpha|}{l\omega} + \frac{|\alpha|}{l\omega}\cos(180 - \angle OO_1P_1) \\ &= 2\frac{|\alpha|}{l\omega} - \frac{|\alpha|}{l\omega}\cos(\angle OO_1P_1) \\ &= \frac{|\alpha|}{l\omega}\left[2 - \cos\left\{\omega(t_1 - t_0)\right\}\right] \qquad 37.\end{aligned}$$

By substituting equation 37 into equation 36, we obtain

$$\overline{P_1H} = \frac{|\alpha|}{l\omega}\left[2 - \cos\left\{\omega(t_1 - t_o)\right\}\right] \cdot \tan\frac{\omega(t_2 - t_1)}{2} \qquad 38.$$

From equations 35 and 38, we obtain

$$\sin\left\{\omega(t_1 - t_0)\right\} = \left[2 - \cos\left\{\omega(t_1 - t_0)\right\}\right] \tan\left\{\frac{\omega(t_2 - t_1)}{2}\right\} \qquad 39.$$

By the concurrent solution of equations 32, 34 and 39, $(t_1 - t_o)$, $(t_2 - t_1)$ and $(t_3 - t_2)$ can be obtained.

From the foregoing description, it can be noted that it is possible to make zero the swing of the rope at the time of stopping the trolley when the trolley is controlled according to the speed pattern shown in FIG. 10 and when the acceleration-deceleration switching points which satisfy equations 32, 34 and 39 are selected. However, as equation 39 is a complicated equation in terms of implicit functions including complicated trigonometrical functions, a complicated and expensive electronic computor is necessary for the simultaneous solution of equations 32, 34 and 39. Incorporation of such an expensive computer into the control system of a crane increases the cost thereof so that at present the control system is not provided with such computer but merely depends upon a mathematical analysis.

The inventor has solved equations 32, 34 and 39 with an electronic computer utilizing the data regarding the rope length and the transverse running speed of the trolley and found that a high accuracy sufficient for the practical use can be obtained from the following equation 40 in which interval $(t_1 - t_o)$ is approximated as the explicit functions of $V\max$, and **1**.

$$t_1 - t_o = a\,|V\max| + bl + c \qquad \text{-40.}$$

where a, b, and c represent constants.

Accordingly, $t_2 - t_1$ and $t_3 - t_2$ can be obtained as follows from equations 32 and 34.

$$t_2 - t_1 = 2(t_1 - t_o) - \left|\frac{V\max}{\alpha}\right| \qquad 41.$$

$$t_3 - t_2 = t_1 - t_o \quad -42.$$

As can be noticed from FIG. **10**, time t_3 (or t_7) represents an instant at which the transverse running speed of the trolley reaches a predetermined ultimate value and at which the difference between the ultimate speed commanded by the trolley controller and the actual running speed of the trolley reduces to substantially zero. Accordingly, by terminating the acceleration or deceleration by detecting this condition it will be not necessary to calculate $t_3 - t_2$ by using equation 42. In other words, it is sufficient to calculate $(t_1 - t_o)$ and $(t_2 - t_1)$ alone by using equations 40 and 41.

The straight lines shown in FIG. **12** show the relationship between the switching time $t_1 - t_o$ and the rope length obtained by solving equations 32, 34 and 39 for the rope length of from 7.5m to 22.5m and the trolley running speed of from 31.25 m/min. to 125m/min. Straight lines shown in FIG. **12** show the solution of equation 40. Thus, FIG. **12** shows that even when the switching time is calculated according to equation **40** of approximation, it is possible to realize sufficiently high practical accuracy for the ranges of the rope length variation and the trolley speed variation encountered in the actual use.

Equations 29, 30 and 31 also show that the stroke of the trolley (the area of the lefthand shaded portion in FIG. **1**) during interval $t_o - t_3$, in which the trolley has accelerated to a maximum speed Vmax after starting is equal to the stroke (the area of the righthand shaded portion in FIG. **1**) during interval $t_4 - t_7$ in which the trolley has decelerated from V*max* to standstill. This method of operation is the result of approximation of the above described analysis in terms of the maximum speed and the length of the rope.

From this it can be understood that it is possible to terminate the swinging motion of the rope when the trolley stops by measuring or calculating the distance S over which the trolley travels from starting until the maximum speed is reached and by issuing a deceleration initiation command signal when the trolley reaches a point spaced from a target stopping position by a required distance.

From the foregoing description, it will be clear that according to the control system described hereinabove, it is possible to substantially reduce to zero the swing of the rope when the trolley is accelerated to a predetermined maximum speed V*max* and when the trolley is brought to stop. With this system, however, as no signal is given as to when the deceleration should be commenced at time t_4, the crane operator must determine by himself such time by relying upon his skill. Accordingly, it is not always possible to correctly stop the trolley at the target position at time t_7.

SUMMARY OF THE INVENTION

It is an object of this invention to provide a novel method and system for controlling a suspension type crane capable of suppressing to substantially zero the swing of the load suspending rope while the crane is running at a constant speed.

Another object of this invention is to provide a novel method and system for controlling a suspension type crane capable of initiating the deceleration at a correct time for stopping it at a predetermined target position without any swinging motion of the rope.

Still another object of this invention is to provide a novel method and system of controlling a suspension type crane capable of operating the same with a minumum time without permitting any swing to the rope while the crane is running at a constant speed and when the crane is stopped, thereby increasing the cargo efficiency. A further object of this invention is to provide a novel acceleration-deceleration pattern signal generating circuit suitable for use in this invention.

According to one aspect of this invention there is provided a method of controlling a suspension type crane which is moved transversely while suspending a load by means of a rope wherein the crane is accelerated at least two times at spaced points to a predetermined maximum speed during the acceleration period, the swing of the rope is minimized when the predetermined maximum speed is reached, the crane is run at the predetermined maximum speed for a predetermined interval, the crane is decelerated from the maximum speed at least two times at spaced points during the deceleration period, and the crane is stopped when the swing of the rope is reduced to a minimum, characterized in that the areas of the acceleration and deceleration periods of the crane are made equal.

According to another aspect of this invention there is provided a control system for a suspension type crane running in the transverse direction, characterized by comprising means for providing a start command signal, means responsive to the start command signal for determining a maximum transverse running speed of the crane corresponding to the starting position and a predetermined target position of the crane, means for providing a deceleration command signal when the crane reaches a point a predetermined distance before the target position, which is determined by the maximum transverse running speed, means for generating a deceleration command signal, and means responsive to the start command signal or the deceleration command signal for providing a predetermined acceleration-deceleration pattern signal corresponding to the maximum transverse running speed, whereby the running speed of the crane is controlled so as to stop the crane at the target position.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings:

FIG. **1** is a diagram showing a typical transverse running speed pattern of the trolley of a suspension type crane which can be realized by the control system of this invention;

FIGS. **2** to **11** inclusive are diagrams useful to explain the principle of this invention;

FIG. **12** is a graph showing the relationship between the switching time and the rope length calculated for various rope lengths and trolley speeds which are used actually;

FIG. **13** is a block diagram of one embodiment of the novel control system of this invention;

FIG. **14** is a block diagram of a modified embodiment of this invention;

FIG. **15** shows a modified speed pattern;

FIG. **16** is a block diagram of a crane control system;

FIG. **17** is a block diagram showing one example of the acceleration-deceleration switching time operating circuit utilized in this invention;

FIG. 18 is a diagram for explaining the operation of the operating circuit shown in FIG. 17;

FIG. 19 shows a block diagram of the speed reference generating circuit controlled by the operating circuit shown in FIG. 17; and

FIG. 20 is a diagram for explaining the operation of the speed reference generating circuit shown in FIG. 19.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 13 shows the construction of one embodiment of the control system of this invention which comprises a deceleration command signal generator A which generates a deceleration commandsignal in accordance with the deviation ΔL of the present position L from the target position Lo for providing a transverse running speed pattern as shown in FIG. 1, a maximum transverse running speed determining unit B which determines the maximum transverse running speed $Vmax$ in accordance with a deviation ΔL corresponding to the distance Lo to the target position and rope length 1 (for the reason to be described later, rope length is not taken into consideration at the present stage of the description), an acceleration-deceleration pattern generator C connected to receive the output from the maximum transverse running speed determining unit B when the deceleration command signal generator A operates for forming the transverse running speed pattern shown in FIG. 1, and a speed controller D for controlling the speed of a motor M for driving the trolley in accordance with the output from the acceleration-deceleration pattern generator C. These component elements will be described in detail in the following.

The deceleration command signal generator A will firstly be described. The distance S over which the trolley which has been running at the maximum speed $Vmax$ should travel before it is stopped in accordance with the speed pattern shown in FIG. 1 can be derived out from equations 29, 30 and 31, thus

$$S = \tfrac{1}{2} V\text{max}\{2(t_1 - t_o) + (t_2 - t_1)\} \qquad 42.$$

Intervals $(t_1 - t_o)$ and $(t_2 - t_1)$ can be obtained from the following equations.

$$\sin\{\omega(t_1 -, t_o)\} = \left[2 - \cos\{\omega(t_1 - t_o)\}\right] \cdot \tan\left\{\frac{\omega(t_2 - t_1)}{2}\right\} \qquad 43.$$

and

$$t_2 - t_1 = 2(t_1 - t_o) - \frac{Vmax}{\alpha} \qquad 44.$$

Instead of using equation 41, an approximate value of distance s can be derived out from equations 42, 44 and the following equation 45 which is an equation of approximation expressed by an explicit function of the maximum speed $Vmax$ and the rope length 1

$$t_1 - t_o = a|V\text{max}| + b1 + c \qquad 45.$$

where a, b and c are constants.

This also corresponds to the distance of running during interval $t_7 - t_6$ shown in FIG. 1 but this distance of running can be obtained by storing the running distance during interval $t_8 - t_3$. This is because the running distances during intervals $t_4 - t_7$ and $t_o - t_3$ are equal as has been mentioned hereinbefore. In any way, the distance S required to stop the trolley has already been determined by the time at which the trolley attains its maximum speed $Vmax$. Such measurement or calculation is required to be made only once during the operation of the crane, and the result is given to the deceleration command signal generator A.

Thus, the deceleration command signal generator A stores a signal corresponding to distance S and operates to compare the deviation ΔL $(= Lo - L)$ of the present position L of the trolley from the target postion Lo, with signal S for producing a deceleration command signal when ΔL becomes equal to S. The deceleration command signal can be generated by switching the speed command for the acceleration-deceleration pattern generator C from $Vmax$ to 0, as shown in FIG. 13.

The maximum transverse running speed determining unit B will now be described. While in the foregoing description it was explained that the maximum transverse running speed $Vmax$ is prescribed, as can be noted, from equation 43 where the maximum speed $Vmax$ and rope length 1 are given it is possible to determine acceleration and decleration intervals $t_1 - t_o$, $t_2 - t_1$, $t_3 - t_2$, $t_5 - t_4$, $t_6 - t_5$ and $t_7 - t_6$.

Accordingly, where the values of $Vmax$ and 1 are given, the distance over which the trolley runs between starting and completion of acceleration, and the distance over which the trolley runs from the maximum speed until it stops will also be determined. For this reason, even when a deceleration command signal is generated at an instant t_3 at which acceleration has been completed thus making $t_3 = t_4$, the trolley runs a ddistance 2S, that is, the sum of the distance S from start to the completion of acceleration and the distance S from the maximum speed to the stop. Accordingly, the running distance Lo is shorter than 2S, so that it is necessary to suitably decrease the maximum speed.

The purpose of the maximum transverse running speed determining unit B is to determine such an optimum maximum transverse running speed. The maximum speed $Vmax$ can be derived from equations 42, 43 and 44 by putting

$$S = \frac{Lo}{2}$$

(In lieu of equation 44, equation 45 can also be used). For this reason, in FIG. 12 the distance between the starting position and the target position is designated by $Lo/2$. As shown in FIG. 12, since the maximum speed $Vmax$ does not vary so much with the rope length 1, it is possible to simplify the control device by ignoring the effect of length 1. FIG. 13 shows such simplified construction wherein a signal representing 1 is not applied to the maximum transverse running speed determining unit B.

Turning now to the acceleration-deceleration pattern generator C, it is comprised essentially of integrators and is constructed and operated to generate a predetermined acceleration-deceleration pattern signal as will be described later in detail in connection with FIGS. 17 to 20. At this stage of description, it is merely pointed out that the deceleration command signal generator A switches the input to the acceleration-deceleration pattern generator C from signal $Vmax$ to a reference signal O at time t_4. Further, a signal representing the rope length 1 is also applied to the pattern generator C for compensenting for the variation in the value of the maximum speed *Vmax* caused by the variation in the rope length 1.

Upon reception of these input signals the acceleration-deceleration pattern generator C generates a pattern signal V_{ref} (as shown in FIG. 13) which is applied to the speed controller D. In response to this pattern signal V_{ref}, the automatic speed control circuit ASC provided for the speed controller D controls the speed of trolley driving motor M. The speed control circuit ASC is provided with a negative feedback circuit including a tachometer generator TG coupled to motor M.

The crane control system shown in FIG. 13 operates as follows. For the sake of description it is assumed herein that the crane is installed in a container yard at a warf for transporting containers between a container ship alongside the warf and the container yard. When an operator provides a command signal for the "Off board commencement", the maximum transverse running speed determining unit B forms a maximum transverse running speed signal *Vmax* corresponding to deviation ΔL $(= Loo)$ of the present position of the trolley from the target position. This signal *Vmax* is applied to the acceleration-deceleration pattern generator C in response to the operation of the deceleration command signal generator A. At the same time, rope length signal 1 is applied to pattern generator C.

In response to these signals the acceleration-deceleration pattern generator C produces a pattern signal in accordance with equation 45. This pattern signal produces a speed pattern which causes the rope swing to decrease to zero at the time t_3 of completing acceleration, that is the speed pattern during the interval $t_2 - t_3$ in FIG. 1.

Since this speed pattern is applied to the transverse speed controller D as a speed reference the trolley is accelerated to the maximum speed *Vmax* according to this speed pattern and the swing of the rope is decreased to zero when the trolley attains the maximum speed. Whereupon, the deceleration command signal generator A operates to compare distance S which is necessary for stopping the trolley and can be derived as described above with the deviation ΔL of the present position of the trolley from the target position, thus applying speed command signal O to the acceleration-deceleration pattern generator C when ΔL becomes equal to S. Then, the integration operation is performed in the reverse direction as has been pointed out before thereby producing a speed pattern that causes the swing of the rope to reduce to zero at and after a time t_7 at which the trolley should be stopped, or the speed pattern during interval $t_4 - t_7$ in FIG. 1. As this speed pattern is applied to the speed controller D, the trolley is caused to run and stop in accordance with this speed pattern and at and after time t_7, the swing of the rope will be decreased to zero. At this time, the trolley and hence the load will be correctly positioned at the target position.

FIG. 14 shows a block diagram of a modification of the control system shown in FIG. 13 in which means for compensating for external disturbances and various errors are added to the control system shown in FIG. 13. A so-called feed forward control system not provided with a feedback circuit as shown in FIG. 13 can be used only in a case wherein the rope swings as expected and there is no error. Actually, however, such a case does not exist. More particularly, measuring errors of the

rope length, the error in the computation of the distance S desired for correct stopping and external distrubances such as the effect of wind are inevitable. For this reason, it is often impossible to reduce to zero the rope swing at the time of stopping the trolley thereby mispositioning the load.

In the control system shown in FIG. 14, a feedback control is incorporated into a feed forward control system. To control the residual swing of the rope to be within a permissible range, a signal $K\theta$ corresponding to the rope swing angle θ immediately prior to the stopping of the trolley is fed back to the transverse running speed controller D. Further, for the purpose of controlling the position error caused by various errors described above to be within a permissible range, a signal, KL produced by amplifying at a suitable gain a quantity corresponding to the difference ΔL between the present position of the trolley when it reaches a point close to the target position of the trolley, and the target position is fed back to the transverse running speed controller D. In this connection, if the swing angle signal $K\theta$ and position deviation signal KL were not properly related, the feedback system would become unstable. Generally speaking, in order to stabilize the feedback system the swing angle signal $K\theta$ and the position deviation signal KL should be positive.

In FIG. 14, a contact *e* is arranged to be closed while the trolley is running in the transverse direction at a uniform speed and during a relatively short interval including the stopping point of the trolley but excluding an interval between t_4 and a point close to t_7, whereas a contact *f* is arranged to be closed immediately before the stopping point of the trolley. With this arrangement, from the starting point to a point at which the acceleration is completed a feed forward control is provided similar to the control system shown in FIG. 13 and when the trolley attains a substantially uniform speed, the feedback control of the rope swing angle is effected thus correcting the swing preventing operation. As will be described later in more detail, upon occurrence of a deceleration command signal the control is returned back to the feed forward control to decelerate the trolley according to a predetermined speed pattern and when the trolley approaches the target stopping position the rope swing angle signal $K\theta$ and the position deviation signal ΔL are fed back thereby providing a correction operation so as to limit the error in the position of the trolley and hence of the load to be within a permissible range.

FIG. 15 illustrates another example of the speed pattern which is different from that shown in FIG. 1 in that $t_1 - t_o \neq t_3 - t_2$ and $t_5 - t_4 \neq t_7 - t_6$. Even with such a modified pattern it is only necessary to make equal the shaded areas on the left and righthand sides. This modified speed pattern is suitable for a case where the period of the pendulum motion is shorter than

$$\frac{|Vmax|}{\alpha}$$

FIG. 16 shows a block diagram of a crane control system to which the control system of this invention is applicable. A load *m* suspended by a rope 1′ is hoisted or lowered by a hoist motor M_M and the length 1 of the rope is detected by a synchro transmitter SY, for example. The hoist motor M_M is energized by a variable voltage source SCR_1 under the control of a speed controller S_1 which is controlled by a hoist controller **101.** The trolley driving motor M is energized by another variable voltage source SCR_2 under the control of a speed controller S_2 (corresponding to speed controller D shown in FIGS. **13** and **14**). There are also provided a switching time computor **102** for computing said equations **42** and **43** to determine acceleration-deceleration switching points in response to a transverse running speed signal V_1 determined by a transverse running controller **100,** a speed signal V_2 generated by a tachometer generator TG_2 coupled to motor M and representing the actual speed of the trolley and a signal l generated by the synchro transmitter SY and representing the length of rope **1'**, and a reference speed signal generator **103** responsive to the output from the switching time computor **102.**

The detail of the switching time computor **102** will be described with reference to FIGS. **17** and **18.** At time t_o (FIG. **18**) when the transverse running controller **100** is operated to the OFF BOARD side while the trolley is at a standstill or under a condition of $V_2 = 0$, then $V_1 = V_{max}$ and this signal will be applied to a signal variation detector Z and to a first addition circuit A_1. In response to the output from the signal variation detection circuit Z, relay R_{yo} detects the operation of the transverse running controller **100,** as shown by a graph "R_{yo}" in FIG. **18.** To the other input of the addition circuit A_1 is applied the speed signal V_2 generated by the tachometer generator TG_2 as an inversion input, and the output ($V_1 - V_2$) from the addition circuit A_1 is applied to an absolute value circuit X to obtain the absolute value $|V_1 - V_2|$ which is applied to a relay amplifier R_yA_1 and to a holding circuit H via the normal open contact R_yO_a of relay R_yO. As shown by a graph "R_y**4**" in FIG. **18,** relay R_y**4** connected to the output of relay amplifier X is deenergized when the output from the absolute value circuit X becomes zero. For a short interval in which the controller **100** is operated, since $V_2 - 0$ and a signal $|V_1 - V_2| = |Vmax|$ is applied to the holding circuit H through contact R_yO_a the holding circuit operates to hold this signal $|Vmax|$. As the contact R_yO_{2a} of relay R_y O is closed, relay R_y**1** is operated which is held energized through contacts R_y4_a and $R_y1_a$until relay R_y**4** is deenergized, as shown by graph "R_y**1**" in FIG. **18.** The output $|Vmax|$ from the holding circuit H is applied to a setter S_1 which sets the constant a, and the output a $|Vmax|max$ is applied to the first input of a second addition circuit A_2. A setter S_2 responsive to the rope length signal **1** from synchro transmitter SY sets the constant b and its output bl is applied to the second input of the addition circuit A_2. A variable resistor RH_1 is provided to set the constant c which is applied to the third input of the addition circuit A_2. Accordingly, addition circuit A_2 produces an output $(a|Vmax| + bl + c)$ which is applied to the inversion input of a third addition circuit A_3 and to the multiplying terminal of the fourth addition circuit A_4. Energization of relay R_y**1** applies a definite voltage produced by a variable resistor RH_2 upon an integrator I_1 via its contact R_y1_{2a} to vary the output of integrator I_1 as shown by graph "I_1" shown in FIG. **18.** The output of integrator I_1 is applied to one input of addition circuit A_3. When the output from integrator I_1 becomes equal to the output $(a|Vmax| + bl + c)$ at time t_1, a relay amplifier R_yA_2 operates to energize relay R_y**2** as shown by a graph "R_y**2**" shown in FIG. **18.** Since a signal corresponding to $(a|Vmax| + bl + c)$ is applied to the inversion input of addition circuit A_3, by suitably selecting the integration gain of integrator I_1 it is possible to make equal the interval $(t_1 - t_o)$ from the time of operation of relay R_y**1** to the time of operation of relay R_y**2** and $(a|Vmax| + bl + c)$. Upon energization of relay R_y**2,** integrator I_2 begins to integrate the constant voltage provided thereto by variable resistor RH_2 through contact R_y1_{2a} and the normal open contact R_y2_a of relay R_y**2,** thus producing an output as shown by a graph I_2 in FIG. **18** which is applied to the noninversion input of the fifth addition circuit A_5. Output

$$\frac{|Vmax|}{|\alpha|}$$

of setter S_3 is applied to the inversion input of the fourth addition circuit A_4 whereas the signal $(a|Vmax| + bl + c)$ is applied to the noninversion input of the addition circuit A_4 and multiplied by **2.** Accordingly, addition circuit A_4 produces an output

$$2(a|Vmax| + bl + c) - \left|\frac{Vmax}{\alpha}\right|$$

which is applied to the inversion input of the fifth addition circuit A_5. Consequently, when the output of integrator I_2 becomes equal to **2**

$$2(a|Vmax| + bl + c) - \left|\frac{Vmax}{\alpha}\right|$$

at an instant t_2 (FIG. **18**) relay amplifier R_yA_3 operates to energize relay R_y**3.** Where the integration gain of integrator I_2 is suitably selected, the interval $(t_2 - t_1)$ from the operation of relay R_y**2** to the operation of relay R_y**3** becomes equal to

$$2(a|Vmax| + bl + C) - \left|\frac{Vmax}{\alpha}\right|.$$

When the transverse running speed V_2 of the trolley becomes equal to the maximum value Vmax corresponding to the speed V_1 given by the transverse running controller **100** at time t_3, the output of absolute value circuit X becomes substantially zero thereby deenergizing relay R_y**4** whereby its contact R_y4_a is opened to deenergize relay R_y**1.** Deenergization of relay R_y**1** opens its normal open contact R_y1_{2a} and closes its normal close contact R_y1b thus reducing to zero the output from integrator I_1. As a result, the output from the third addition circuit A_3 becomes zero to deenergize relay R_y**2.** Thus, the integrator I_2 is reset thereby deenergizing relay R_y**3.** In this manner, concurrently with the deenergization of relay R_y**4,** relays R_y**2** and R_y**3** are also deenergized.

Assume now that the transverse running controller **100** is returned to the "STOP" position while the trolley is running at a speed corresponding to the output V_1 from the controller **100** in the direction of OFF BOARD. Under these conditions, when the signal V_1 varies from $Vmax$ to "0", the signal variation detector Z operates to momentarily energize relay R_y O. Because, since $V_1 = 0$ and $V_2 = Vmax$, again the relation $|V_1 - V_2| = |Vmax|$ can be obtained. Thereafter the control system operates in the same manner as described above in connection with the operation when the controller **100** is moved to OFF BOARD position from the STOP position.

For this reason, the interval $(t_1 - t_o)$ between the operations of relays R_y1 and R_y2 is equal to $(a|Vmax| + bl + c)$ whereas the interval $(t_2 - t_1)$ between the operations of relays R_y2 and R_y3 is equal to

$$2(a\ |Vmax| + bl + c) - \left|\frac{Vmax}{\alpha}\right|.$$

When the trolley stops, relay R_y4 is deenergized and integrators I_1 and I_2 are reset.

When the transverse running controller **100** is moved to the ON BOARD position while the trolley is stopped, $V_1 = -Vmax$ and $V_2 = 0$ so that again the relation $|V_1 - V_2| = |Vmax|$ holds and the integration of the switching time is performed in the same manner as the foregoing case in which the controller **100** was moved to the OFF BOARD position.

As has been described above, at all times the switching time computer oprates to make equal (that is satisfies equation 40) the interval $(t_1 - t_o)$ between the operations of relays R_y1 and R_y2 and $(a\ |Vmax| + bl + c)$ and to make equal the interval $(t_2 - t_1)$ between the operations of relays R_y2 and R_y3 and

$$2(a\ |Vmax| + bl + c - \left|\frac{Vmax}{\alpha}\right|$$

(which satisfies equation 43).

Accordingly, by controlling the speed reference of the trolley with the output of the switching time computer **102** shown in FIG. **17** it is possible to control the speed of the trolley according to the pattern shown in FIG. **1**.

FIG. **19** is a block diagram showing one example of a speed reference generator wherein the speed reference of the trolley is controlled by the output from the switching time computer shown in FIG. **17.** The transverse running speed controller **100,** addition circuit A_1 and tachometer generator TG are identical to those shown in FIG. **17.** The output of the addition circuit A_1 is applied to a relay amplifier R_yA_5 through a diode D_1 and to a relay amplifier R_yA_6 through a diode D_2 which is poled oppositely with respect to diode D_1. Relay R_y5 is energized when the addition circuit A_1 produces a positive output, whereas relay R_y6 is energized when the addition circuit A_1 produces an output of the negative polarity. A variable resistor RH_3 is provided to set a variable speed and the output thereof is applied to the noninversion input of an addition circuit A_6 through the normally closed contact R_y5a of relay R_y5 and to the inversion input of the addition circuit A_6 through the normally opened contact R_y6a of relay R_y6. The output of the addition circuit A_6 is applied to the noninversion input of an integrator I_3 via the normally opened contact R_y1_{3a} of relay R_y1 shown in FIG. **17** and to the inversion input of the integrator I_3 via the normally opened contact R_y2_{2a} of relay R_y2 and the normally closed contact R_y3_b of relay R_y3. The inversion input "2" of the integrator I_3 shows that the inverted input signal is doubled, and the output of the integrator I_3 is applied as a speed reference signal to the speed controller S_2 which controls the trolley driving motor M as shown in FIG. **16.**

The control system shown in FIG. **19** operates as follows. When the transverse running controller **100** is moved to the OFF BOARD position from OFF position at times t_2, FIG. **20,** where the trolley is not operative that is $V_2 = 0$, then $V_1 - V_2 > 0$, and relay R_y5 is energized to close its normally opened contact R_y5a. As described above, since relay R_y1 is energized when the controller **100** is operated, its normally opened contact R_y1_{3a} is also closed. Accordingly a signal $+|\alpha|$ is applied to the noninversion input of the inverter I_3 so that the output thereof increases linearly with an acceleration of $+|\alpha|$. At time t_1 relay R_y2 is energized as described above to close its normally opened contact R_y2_{2a}. At this time, relay contact R_y3_b has been closed so that the output from the addition circuit A_6 is also applied to the inversion input of the integrator I_3. Thus, its overall input will be $+|\alpha| - 2|\alpha| = -|\alpha|$. Accordingly, the output from the integrator I_3 decreases with a deceleration of $-|\alpha|$ during an interval between the closure of normally opened contact R_y2_{2a} and the opening of normally closed contact R_y3_b. When relay R_y3 is energized to open its normally closed contact R_y3_b at time t_2, input $+|\alpha|$ alone will be applied to the noninversion input of the integrator I_3 whereby the output thereof increases again with the acceleration of $+|\alpha|$. When the running speed of the trolley becomes equal to the speed V_1 commanded by controller **100** at time t_3, relay R_y5 is deenergized to open its normally opened contact R_y5_a thus removing the input from integrator I_3. Consequently, the output thereof does not vary but maintains a defenite value. At this time, since relays $R_y1 - R_y3$ are denergized, their normally opened contacts R_y1_{3a} and R_y2_{2a} are opened and normally closed contact R_y3_b is closed.

When the trolley is stopped at t_4, then $V_1 = 0$ and $V_1 - V_2 = Vmax < 0$. Accordingly, relay R_y6 is energized to close its normally opened contact R_y6_a. Concurrently therewith, relay R_y1 is also energized as described above to close its normally opened contact R_y1_{3a}. As a result, a signal $-|\alpha|$ is impressed upon the integrator I_3 so that the output thereof decreases with a deceleration of $-|\alpha|$. At time t_5, relay R_y2 is energized to close its normally opened contact R_y2_{2a} whereby the output from the integrator I_3 increases with the acceleration of $+|\alpha|$. At time t_6, relay R_y3 is energized to open its normally closed contact R_y3_b. Then the input to the integrator I_3 becomes $-|\alpha|$ and the output thereof decreases again with the deceleration $-\alpha$. As the trolley stops, $V_2 = 0$, so that relay R_y6 is deenergized and relays R_y1 to R_y3 restore their original states.

Since $t_1 - t_o$, FIG. **20**, is equal to $(a\ |Vmax| + bl + c)$, $t_2 - t_1$ is equal to

$$2(a\ |Vmax| + bl + c) - \left|\frac{Vmax}{\alpha}\right|$$

and since $t_1 - t_o = t_3 - t_2$, by utilizing the output of integrator I_3 as the speed reference for the trolley driving motor it is possible to make the rope swing to become zero when the trolley attains the maximum speed and when the trolley comes to stop.

In the foregoing description while the speed reference signal applied to the trolley driving motor was assumed to have a rectangular waveform as shown in FIG. **20,** where the control system is incorporated with a speed limiting circuit or an armature current limiting circuit, the speed reference signal will have a stepped waveform.

Further, the control system described above is of the feed forward control type wherein the acceleration-deceleration switching points were determined by taking into consideration the speed command signal given by the transverse running controller, the transverse running speed of the controller, and the rope length. Actually however, there are such external disturbances as the wind pressure acting upon the load, spreader, crab and rope, measuring errors in the rope length and trolley speed, and errors of the computer. Where the effect of such external disturbances is substantial, with the feed forward control, there may be a case wherein the swing of the rope exceeds a predetermined limit when the trolley attains the constant speed or when the trolley comes to stop.

Such residual rope swing can be eliminated by adding to the feed forward control system a well known feedback system wherein the swing angle or swing angular velocity of the rope is detected when the trolley attains the uniform speed or stops for negatively feeding back the detected quantity to the transverse speed reference as has been described in connection with FIG. **14.**

Two integrators I_1 and I_2 utilized in the circuit shown in FIG. **17** may be combined into a single integrator in which case the inversion input to the addition circuit A_4 should be multiplied by a factor of 3.

Further it will be clear that various relays can be substituted by semiconductor elements, or another type of contactless relay means.

As described hereinabove this invention provides an automatic control system for a suspension type crane running in the transverse direction wherein the maximum transverse running speed is determined corresponding to the distance between the starting position and a predetermined target position at which the crane is to be stopped and, a deceleration command signal is provided when the crane reaches a point a predetermined distance before the target position, which is determined by the maximum transverse running speed and a predetermined acceleration-deceleration pattern signal corresponding to the maximum transverse running speed. Accordingly, the operator is required to initiate only the start signal and thereafter the crane is operated according to the acceleration-deceleration pattern so as to run the crane at said maximum speed while maintaining at zero or substantially at zero the swing of the rope and to correctly stop the crane at the target position when the swing angle of the rope is reduced to zero or substantially to zero thereby greatly reducing the load on the crane operator. Further, this invention provides a subtime optimal control system because the negative feedback is applied only when the control deviates from a prescribed pattern, thus not only improving the accuracy of the control without increasing the time required for the crane to reach the target position but also improving the cargo efficiency.

It will be clear that the function of at least one element can be performed by an electronic computer, that the control system can be applied to the control of the carriage of a crane and that the acceleration-deceleration pattern may be different from those illustrated. For example, the acceleration and deceleration during the acceleration and deceleration periods may be made three or more than three times.

1. A control system for a suspension type crane running in the transverse direction, the improvement comprising means for providing a start command signal, means responsive to said start command signal for determining a maximum transverse running speed of said crane corresponding to the distance between the starting position and a predetermined target position of said crane, means for generating a deceleration command signal when said crane reaches a point a predetermined distance before said target position, which is determined by said maximum transverse running speed, and means responsive to said start command signal or said deceleration command signal for providing a predetermined acceleration-deceleration pattern signal corresponding to said maximum transverse running speed, whereby the transverse running speed of said crane is controlled so as to stop said crane at said target position.

2. The control system according to claim **1** wherein said crane includes a transversely running trolley operated by an electric motor and suspends a load by means of a rope, and said control system further comprises a speed controller responsive to said acceleration-deceleration pattern signal for controlling said motor.

3. The control system according to claim **2** which further comprises means for generating a speed signal proportional to the speed of said motor and means for negatively feeding back said speed signal to said speed controller.

4. The control system according to claim **3** which further comprises means for applying a signal corresponding to the swing angle of said rope at a point immediately prior to the stop of said trolley to said speed controller.

5. The control system according to claim **4** which further comprises means for applying to said speed controller a signal corresponding to the distance between said target position and the present position of said trolley.

6. The control system according to claim **1** wherein said deceleration command signal generating means includes means for comparing the distance S between a point at which deceleration of said crane is commenced and said target position with the deviation ΔL of the present position of said crane from said target position for generating said deceleration command signal when said deviation ΔL becomes equal to said distance S.

7. The control system according to claim **1** wherein said means for providing said acceleration-deceleration pattern signal comprises an integrator which is connected to integrate said maximum transverse running speed or a reference signal in accordance with the operation of said deceleration command signal generating means.

8. The control system according to claim **7** wherein said integrator includes means to reverse said pattern signal.

9. The control system according to claim **2** which further includes a switching time computer comprising means responsive to the operation of a controller for said trolley and the speed of said trolley driving motor for producing a signal $|Vmax|$ where $Vmax$ represents a predetermined maximum transverse running speed of said trolley;

means for producing a signal $(a\,|Vmax|\ +0\ b1 + c)$, where a, b and c are constants, and 1 the length of the rope;

means for producing a signal

$$\left|\frac{Vmax}{\alpha}\right|$$

where α represents the acceleration of said trolley;

a first integrator for integrating a predetermined constant voltage during the acceleration period of said trolley;

first and second relay means;

means for energizing said first relay means when the output of said first integrator becomes equal to $(a |Vmax| + b1 + c)$;

a second integrator responsive to the operation of said first relay means for integrating a predetermined constant voltage;

means to produce a signal

$$2 (a |Vmax| + bl + c) - \left|\frac{Vmax}{\alpha}\right|$$

and means for energizing said second relay means when the output from said second integrator becomes equal to

$$2 (a |Vmax| + bl + c) - \left|\frac{Vmax}{\alpha}\right|;$$

and a speed reference generator comprising a third integrator responsive to the operation of said first and second relay means for applying a signal $+|\alpha|$ or $-|\alpha|$ to said speed controller of said trolley driving motor.

10. The control system according to claim **9** which further comprises means for detecting the polarity of a signal $V_1 - V_2$, where V_1 represents a constant voltage start signal applied by said trolley controller and V_2 the actual transverse running speed of said trolley; means responsive to the operation of said polarity detecting means for applying a signal $+|\alpha|$ or $-|\alpha|$ to one input of said third integrator, and means responsive to the operation of said first and second relay means for applying a signal **2** α to the other input of said third integrator.

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