(12) UK Patent Application (19) GB (11) 2 280 045 (13) A

(43) Date of A Publication 18.01.1995

(21) Application No 9314682.7

(22) Date of Filing 15.07.1993

(71) Applicant(s)
Daewoo Engineering Company

(Incorporated in the Republic of Korea)

12-3 Yoido-dong, Yongdeungpo-gu, Seoul 150-010, Republic of Korea

Korea Advanced Institute of Science and Technology

(Incorporated in the Republic of Korea)

373-1 Kuseong-dong, Yuseong-gu, Taejeon 305-701, Republic of Korea

(72) Inventor(s)
Intak Bae
Zeungnam Bien

(51) INT CL[6]
B66C 13/06

(52) UK CL (Edition N)
G3N NGDA N265B N410
B8H HGDA HG25

(56) Documents Cited
EP 0467783 A **EP 0394147 A** **US 4717029 A**
US 4603783 A **US 4512711 A**

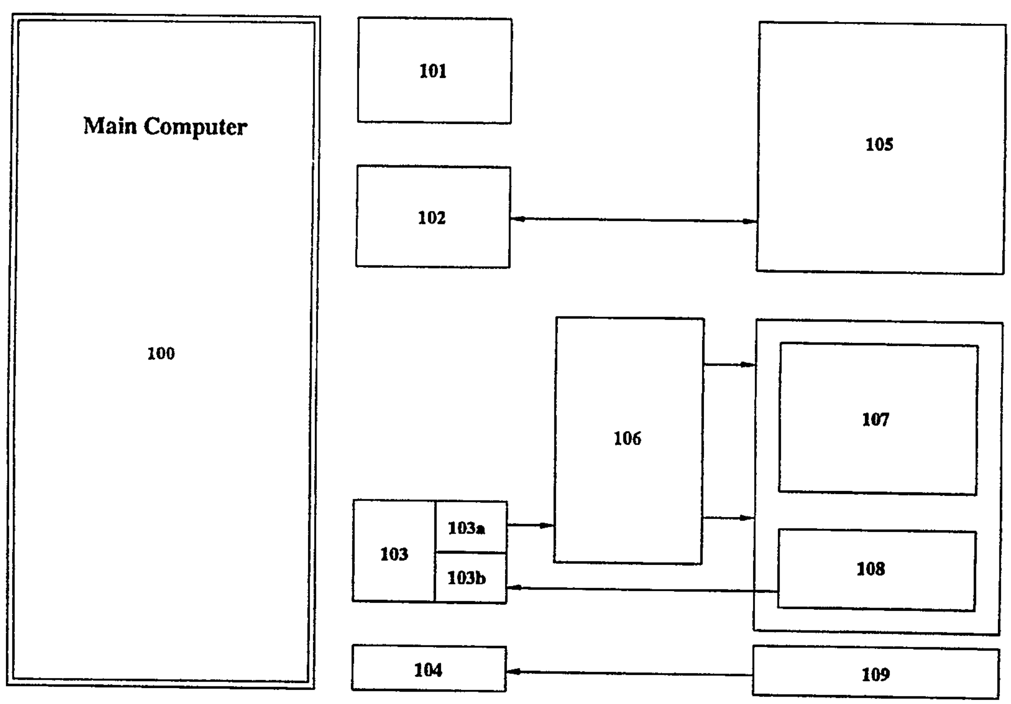
(58) Field of Search
UK CL (Edition L) **B8H HGDA, G3N NGD NGDA NGDB NGE3A NGE3AA NGE3AB NGE3AC**
INT CL[5] **B66C 13/06 13/22 13/30 13/48**
ONLINE DATABASES : WPI

(74) Agent and/or Address for Service
D Young & Co
21 New Fetter Lane, LONDON, EC4A 1DA, United Kingdom

(54) Anti-swing automatic control systems for unmanned overhead cranes

(57) An anti-swing automatic control system for unmanned overhead cranes is provided which calculates and controls an appropriate velocity profile to eliminate swings of an object which is being moved hung on a wire rope when transporting it using an overhead crane. The anti-swing automatic control system can move an object to a destination with minimum swing by controlling the velocity of the crane utilizing a velocity profile generator and a fuzzy logic controller etc.

Fig. 10



GB 2 280 045 A

Fig. 1

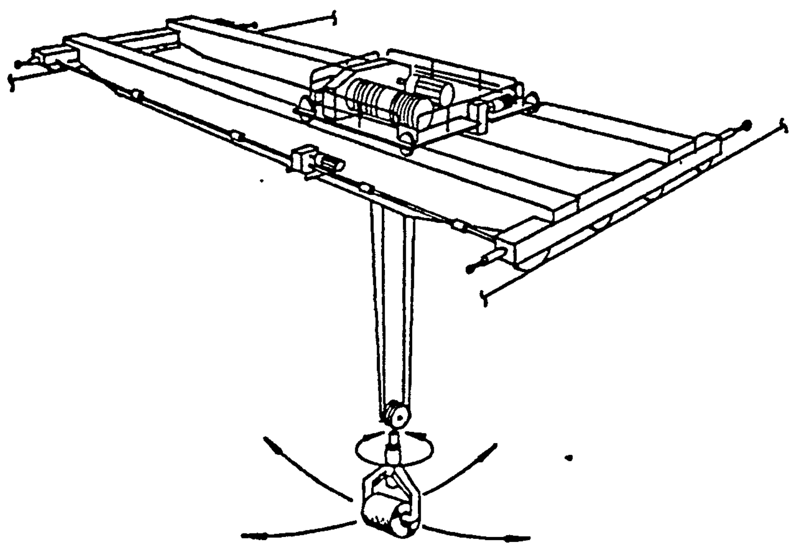


Fig. 2

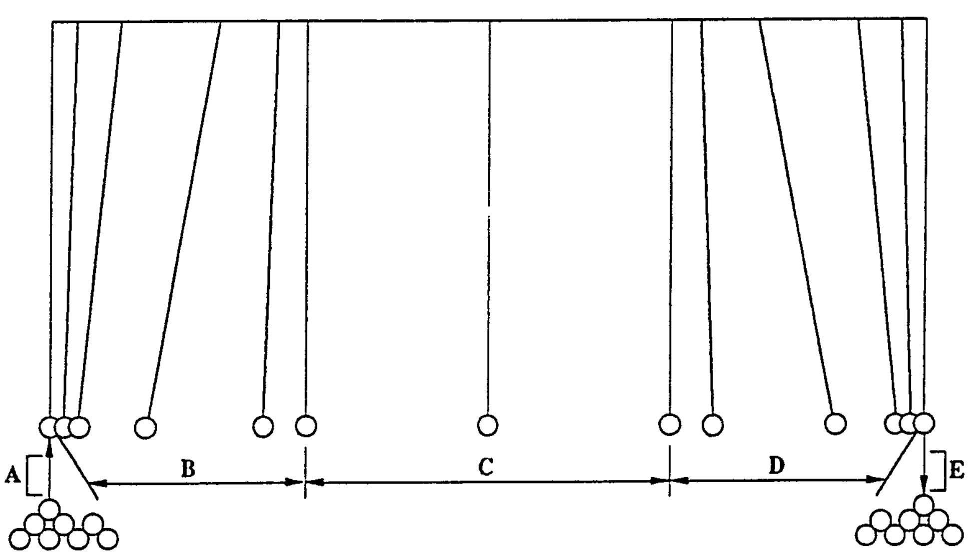


Fig. 3

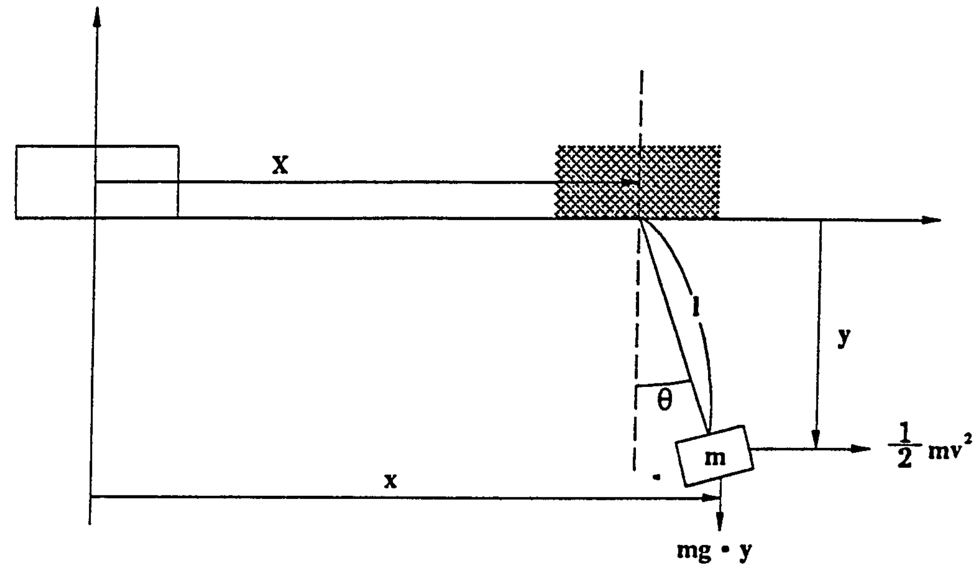


Fig. 4

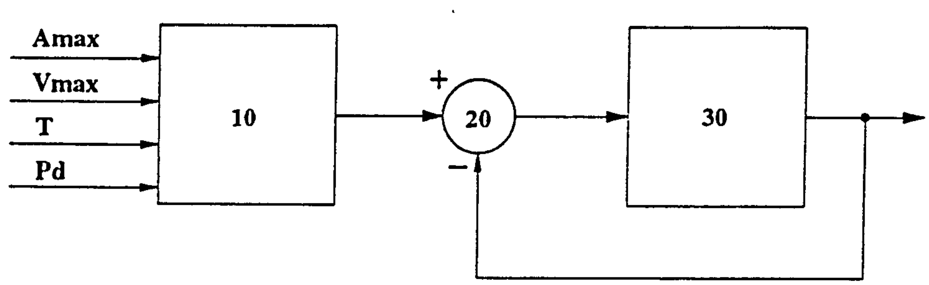


Fig. 5

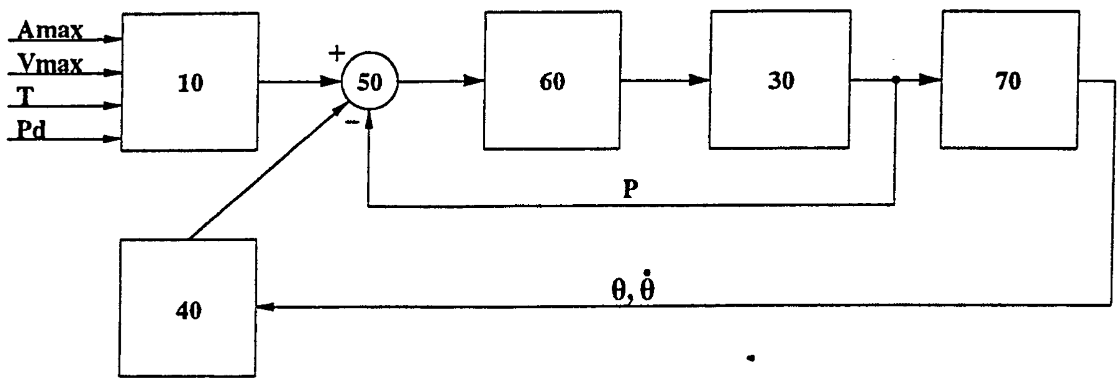

Amax
Vmax
T
Pd
10
+
50
-
60
30
70
P
40
θ, θ̇

Fig. 6

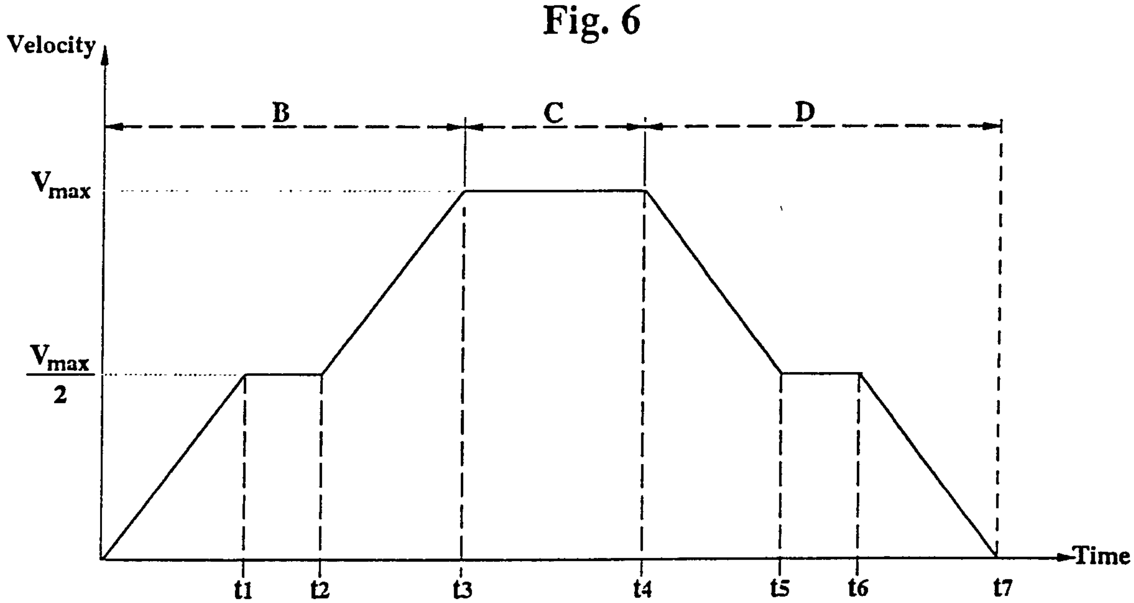

Velocity
B
C
D
Vmax
Vmax/2
t1
t2
t3
t4
t5
t6
t7
Time

Fig. 7

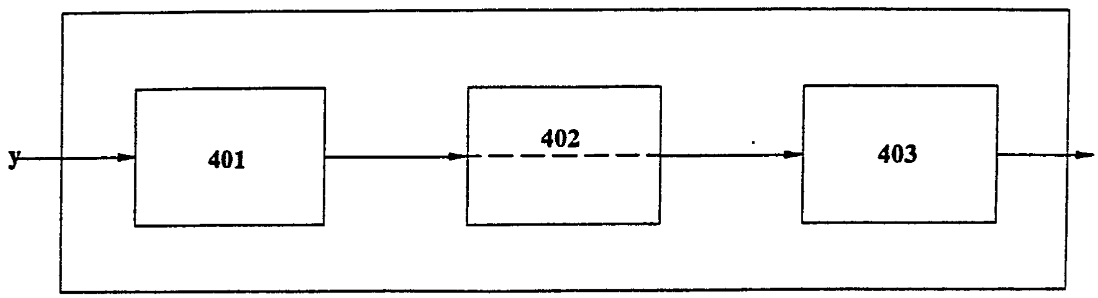


Fig. 8

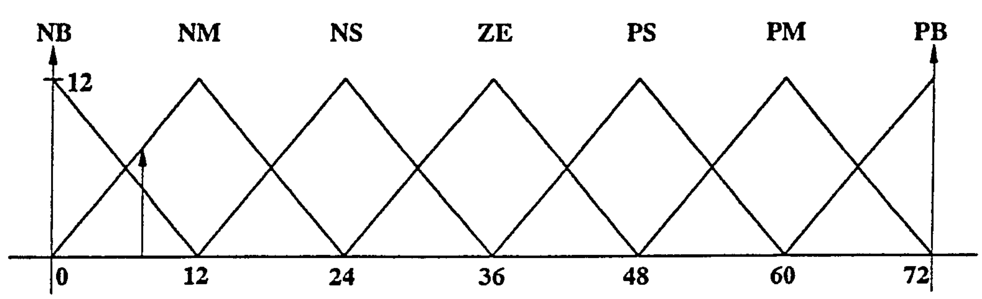


Fig. 9

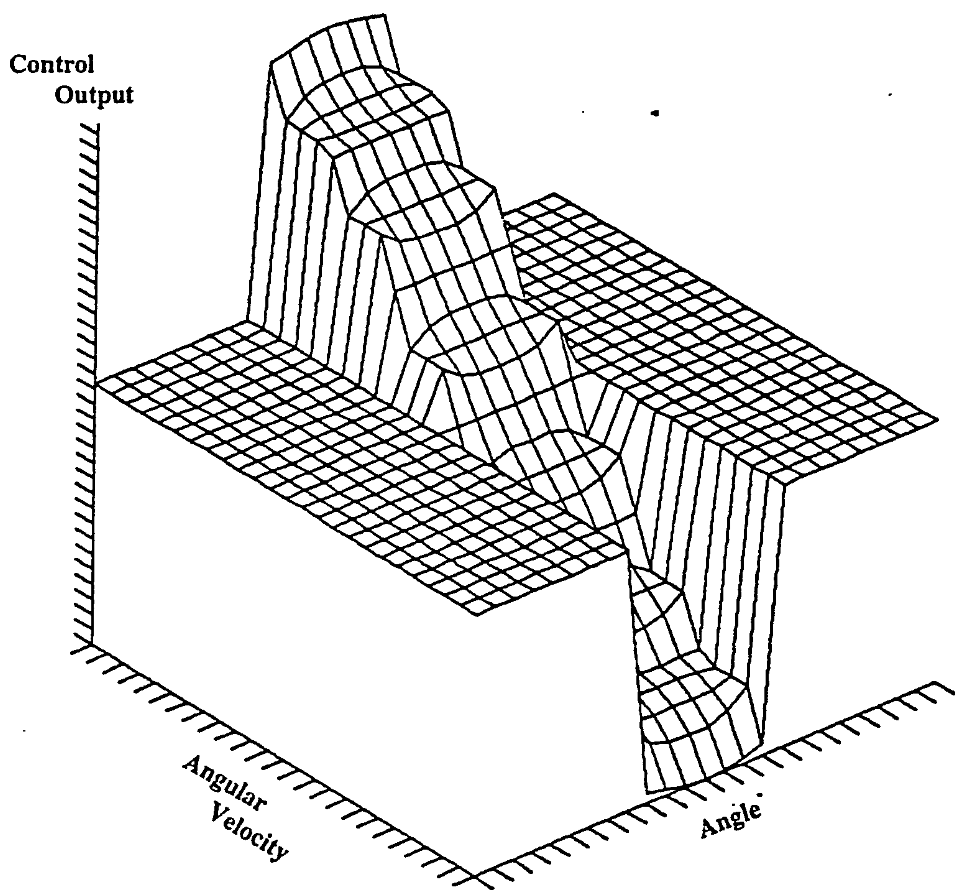


Fig. 10

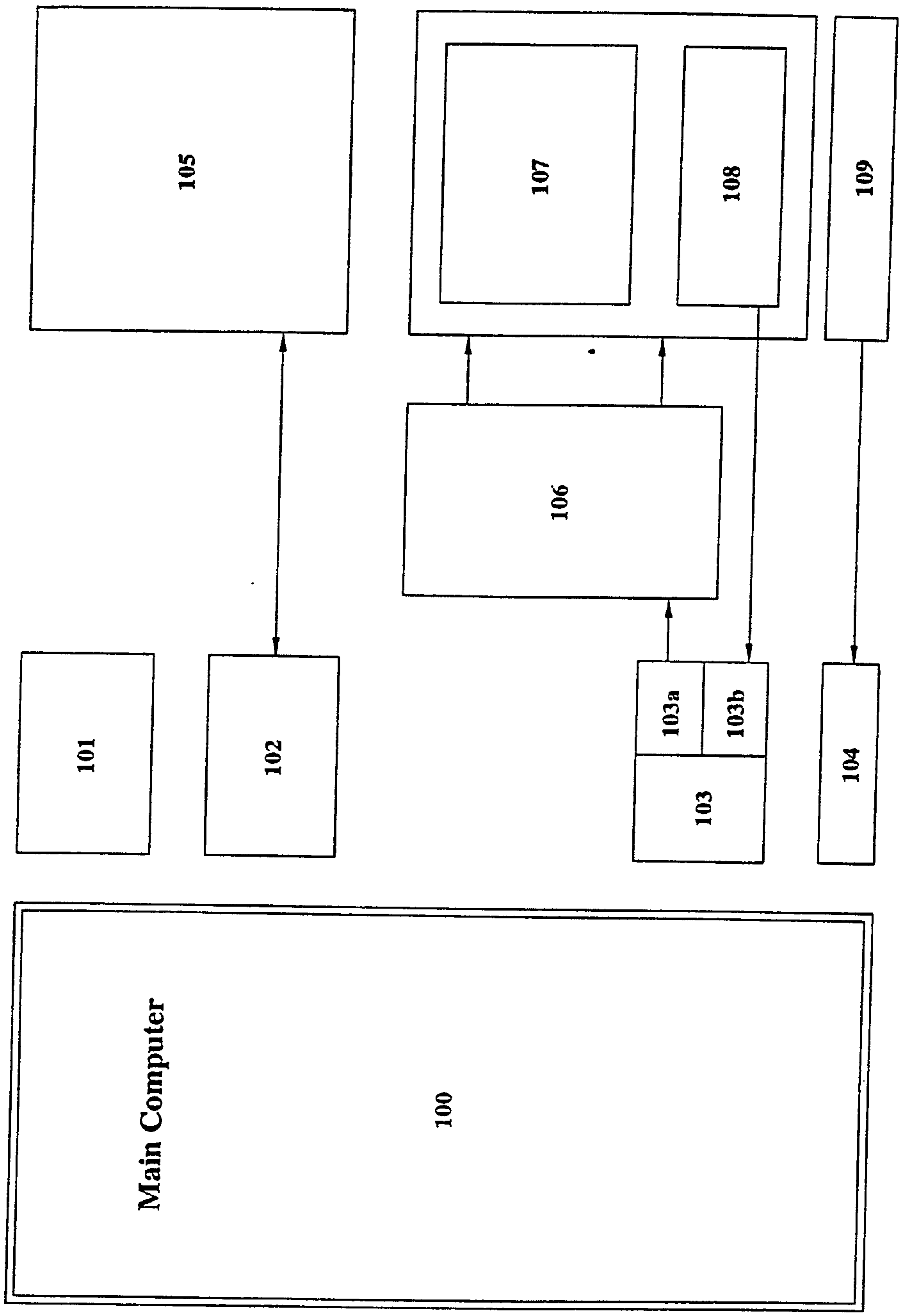
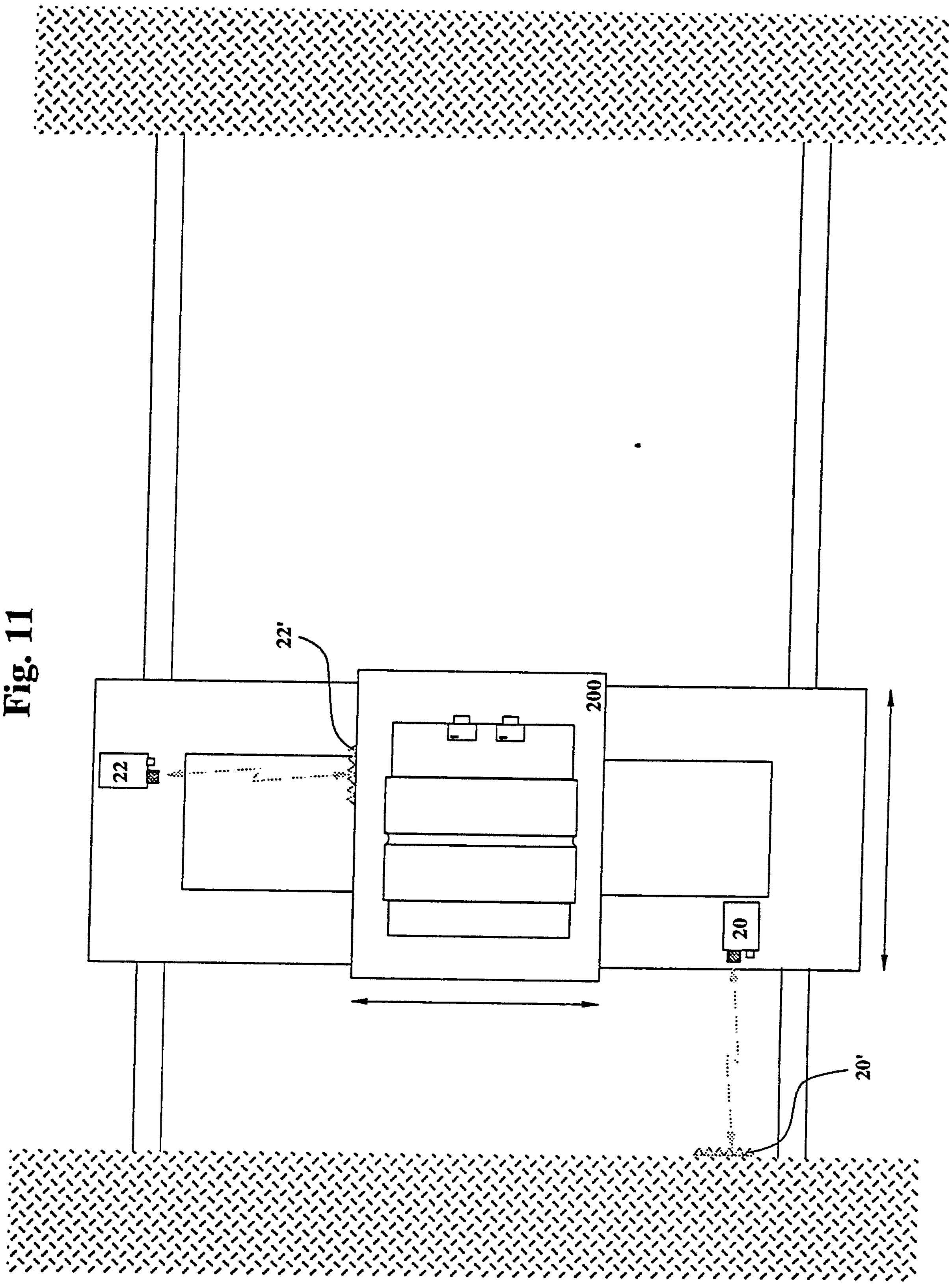

105
107
108
109
106
101
102
103a
103b
103
104
Main Computer
100

Fig. 11



2280045

ANTI-SWING AUTOMATIC CONTROL SYSTEMS FOR UNMANNED OVERHEAD CRANES

This invention relates to anti-swing automatic control systems for unmanned overhead cranes which can calculate an appropriate velocity profile and control a driving mechanism of the cranes to eliminate swings of the objects being moved hung on ropes.

Recently, automation for material handling processes has been carried out as one of various efforts to achieve overall automation at factories and fields. An overhead crane, which is one of material handling machines, is utilized to transport heavy objects from one point to the other using wire ropes. The exterior shape and operational outlook of this overhead crane are shown in Fig. 1.

As seen in Fig.2, motional profile of such cranes is classified into the following three motions; picking and hoisting the object to an appropriate height {A}; travelling to the destination {B-C-D}; lowering and placing the object to the target position {E}. The travelling zone, that is B-C-D, is divided again into the zones of acceleration, constant speed, deceleration, stop and compensation.

The greatest problem in transporting objects utilizing a general overhead crane is the residual swing of the object hung on wire ropes when the crane is stopped at a target position. In conventional manual-operated cranes, skilled operators control the driving torque with his own experience during travelling so as to minimize the residual swing at the destination position, and then control the crane back and forth to eliminate this residual swing.

According to one aspect of the invention there is provided an anti-swing automatic control system for unmanned overhead cranes comprising: the velocity profile generator generating position data computed from the predetermined velocity profile when an object is moved from one position to a destination, the crane motor, and the sensing device which deducts the outputs of said crane motors from the outputs of said velocity profile generator and controls said crane motors by means of the velocity profile.

Respective further aspects of the invention are as set forth in claims 4 and 9.

Embodiments of the invention provide an anti-swing automatic control system for unmanned overhead cranes which overcomes work limits of aforementioned conventional manual-operated overhead cranes. A velocity profile generator and a fuzzy logic controller, which calculate optimum velocity profile according to the velocity profile of the overhead crane and control with a fuzzy control logic, are developed, and relevant hardwares and softwares are organised for this anti-swing automatic control system, thus achieving high accuracy in controlling the overhead cranes.

In embodiments of the invention, the whole of the previous process of manual operation is automated and high performance and reliability are achieved.

An embodiment of the invention will now be described, by way of example, with reference to the accompanying drawings in which:

Fig.1 shows a schematic diagram of exterior shape and operational outlook of a general overhead crane,

Fig.2 shows the motional profile of an overhead crane,

Fig.3 shows the model of the dynamic system of an overhead crane embodying the invention,

Fig.4 shows the block diagram of the velocity profile generator of this embodiment,

Fig.5 shows the block diagram of overall control system of this embodiment,

Fig.6 shows the optimum velocity profile for the control system of this embodiment,

Fig.7 shows the block diagram of the fuzzy logic controller of this embodiment,

Fig.8 shows the membership function according to Singleton Method in the fuzzification interface of this embodiment,

Fig.9 shows the contour graph of control output values for the inputs of defuzzification interface,

Fig.10 shows the overall block diagram for the unmanned overhead crane control system of this embodiment,

Fig.11 shows the installation plan drawing for the unmanned overhead crane control system of this embodiment .

Fig.3 shows the model of the dynamic system of an overhead crane. The motion of an overhead crane can be modelled according to the Lagrange equation, as represented by equation (1) ;

$$L = W - P \qquad \text{.................................... (1)}$$

where, W : kinetic energy of the system,

P : potential energy of the system.

Also,

$$\ddot{\theta} = \frac{g}{l}\theta + \frac{a}{g} \qquad \text{.................................... (2)}$$

where, θ : angle of swing,

$\ddot{\theta}$: angular acceleration of swing,

a : horizontal acceleration of the trolley,

g : acceleration of gravity,

l : length from the center of swing to the center of the load

Therefore, the system model can be represented as follows;

$$\dot{X} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & -g/l & 0 \end{bmatrix} X + \begin{bmatrix} 1 \\ 0 \\ 1/l \end{bmatrix} u$$

while,

$$X = \begin{bmatrix} \dot{x} \\ \theta \\ \dot{\theta} \end{bmatrix}$$

where, $\dot{x}$: velocity of the trolley,

θ : angle of swing,

$\dot{\theta}$: angular velocity,.

Therefore, it can be understood that the swing of the wire ropes of the overhead crane is affected by the acceleration of the crane, and eventually the crane can be moved to a destination with minimum swing by controlling the velocity of the crane.

Fig.4 shows the block diagram of the velocity profile generator, by which the velocity profile is generated and an object can be transported according to this predetermined velocity profile from one position to the destination by an overhead crane.

The velocity profile generator (10) calculates and composes optimum velocity profile using the maximum acceleration (A_{max}), the maximum velocity (V_{max}), the period of swing (T) and destination point (P_d), and then controls the crane motor (30) using this profile.

The controller (20) deducts outputs of the crane motor (30) from outputs of the velocity profile generator (10), thus creating velocity profile, and then controls the crane motor (30) which consists of AC motors and encoders.

Therefore, since the crane motor(30) has a position feed back, it outputs the position calculated based on the velocity profile from the velocity profile generator (10).

Fig.5 shows the block diagram of the overall control system to which a fuzzy logic controller is applied to compensate the residual swing after arrival. This overall control system is composed of a velocity profile generator (10) which generates position data computed by the predetermined velocity profile when the object is moved from one position to the destination; a fuzzy logic controller (40) which senses the angle of swing θ and the angular velocity of swing $\dot{\theta}$ from the motion of crane (70) and compensates the swings utilizing the control algorithm based on the fuzzy rules (402); a sensing device (50) which deducts the outputs of the fuzzy logic controller (40) and the position signal P of the crane motor (30) from the outputs of the velocity profile generator (10); a controller (60); crane motors (30) and the crane dynamics (70).

Fig.6 shows the optimum velocity profile for the system embodying the invention, in which the travelling(and/or traversing) motion of the overhead crane is (are) classified into the three zones of acceleration (B), maximum velocity (constant velocity) (C) and deceleration (D). If the angle of swing θ becomes 0° when the velocity of the trolley in the acceleration zone B reaches the maximum velocity, the angle of swing θ is maintained at 0° through the maximum velocity (constant velocity) zone C, because angular velocity of swing $\dot{\theta}$ is maintained at 0 throughout the zone. The deceleration has the opposite process so as to be symmetrical to the acceleration.

Fig.7 shows the block diagram of the fuzzy logic controller. The fuzzy logic controller is composed of a fuzzification interface (401), a fuzzy inference engine, a defuzzification interface (403) and a fuzzy rule (402).

Here, the fuzzification interface (401) measures crisp input values and fuzzificates them according to the Singleton Method as shown in Fig.8. The abbreviation NB denotes negative big, NM negative medium, NS negative small, ZE zero, PS positive small, PM positive medium and PB positive big, respectively.

The fuzzy inference engine deduces fuzzy outputs for fuzzy inputs using the fuzzy rule. It calculates appropriate values based on implications.

The defuzzification interface (403) converts the fuzzy output values into the crisp output values. The actual control value, in case of 72 scaling mapping as an example, is calculated by the following equation, which is derived by CGM (Center of Gravity Method) ;

$$U_o = \frac{\sum_{j=0}^{72} \mu(u_j) \cdot u_i}{\sum_{j=0}^{72} \mu(u_j)} \qquad \cdots\cdots\cdots (3)$$

where, U_o is the crisp control output value and (u_j) is the membership value of u_j.

The three dimensional contour graph of the control output values for the inputs to the Defuzzification Interface (403) is shown in Fig. 9, while table 1 shows Fuzzy Rule (402) which reads, for example, as follows;

if θ is ZE and $\dot{\theta}$ is PM, it is when the angle is changing gradually from ZE to PM so that PM is taken as the control output giving an effect of restraining the swing.

The fuzzy rule (402) uses IF-THEN rule, where;

if the angular velocity is NB and the angle is ZE, then the acceleration of trolley is NB;

if the angular velocity is NM and the angle is ZE, then the acceleration of trolley is NM;

if the angular velocity is NS and the angle is ZE, then the acceleration of trolley is NS;

if the angular velocity is ZE and the angle is ZE, then the acceleration of trolley is ZE;

if the angular velocity is PS and the angle is ZE, then the acceleration of trolley is PS;

if the angular velocity is PM and the angle is ZE, then the acceleration of trolley is PM, and

if the angular velocity is PB and the angle is ZE, then the acceleration of trolley is PB.

These rules are organized into Table 1 as the Fuzzy Rule (402) for this embodiment.

Table 1

angular velocity($\dot{\theta}$) / angle (θ)	NB	NM	NS	ZE	PS	PM	PB
NB							
NM							
NS							
ZE	NB	NM	NS	ZE	PS	PM	PB
PS							
PM							
PB							

Fig. 10 shows the overall block diagram of this embodiment, where the main computer (100), which is a general purpose computer, is equipped with the velocity profile generator (10) in Fig.4 and the fuzzy logic controller (40) with the velocity profile generator (10) in Fig. 5 so that it can calculate the velocity profile and perform the anti-swing control through the fuzzy logic controller (40) to eliminate the swing of the object which is being moved hung on the wire rope when transporting an object utilizing an overhead crane (200) shown in Fig.11.

To the main computer (100) are connected a CPU (101) for controlling the input-output signals, a communication card (102), a D/A converter and counter (103), and an A/D converter (104).

The communication card (102) is connected to the distancemeter (105) via an RS-422 communication which is not susceptible to external disturbances, the distancemeter (105) is composed of an X-axis distancemeter (20) and a Y-axis distancemeter (22), as shown in Fig.11, to measure an absolute position of the crane in real time. Therefore, the object can be moved to the destination with minimum swing by controlling the velocity of the crane since both of the longitudinal and transverse position of the crane are sensed by the distancemeter (105) and transmitted to the main computer via the communication card (102) so that the velocity profile generator (10) or the velocity profile generator (10) together with the fuzzy logic controller (40) are operated.

As mentioned above, the main computer (100) eliminates the swing of the object which is being moved hung on the wire rope when transporting the object by appropriately controlling the crane motor (30) through the velocity profile generator (10) or the velocity profile generator (10) with the fuzzy logic controller (40), which actually generate(s) the velocity profile. This velocity profile is delivered to the motor controller (106) via a D/A converter (103a) of I/O ports (103) to operate AC motors (107) which are travelling motors, traversing motors and hoisting motors.

Upon driving the AC motor (107) of the crane motor (30), pulses are generated by incremental encoders (108) and transmitted to the counter (103b), thus enabling the main computer to count revolutions of a wheel on a rail.

When an overhead crane (200) shown in Fig.11 transports an object along X or Y-axis, the swing angle of the object which is being moved hung on the wire rope is measured by the swing angle sensor (109) and then transmitted to the main computer (100) via the A/D converter (104) so that the main computer (100) controls the AC motors (107) of the crane motor (30) via a D/A converter (103a) and the motor controller (106) as described above to eliminate the residual swing and position error to a certain limit at the destination.

While a preferred embodiment of the invention has been described, it will be understood by those skilled in the art that various changes may be made therein without departing from the scope of the invention.

CLAIMS

1. An anti-swing automatic control system for unmanned overhead cranes comprising;

the velocity profile generator (10) generating position data computed from the predetermined velocity profile when an object is moved from one position to a destination,

the crane motor (30), and

the sensing device (50) which deducts the outputs of said crane motors (30) from the outputs of said velocity profile generator (10) and controls said crane motors (30) by means of the velocity profile.

2. The anti-swing automatic control system for unmanned overhead cranes of Claim 1, wherein said velocity profile utilizes the maximum acceleration A_{max} of said overhead crane, the maximum velocity V_{max}, the period of swing T of an object which is being moved hung on the wire ropes, and the Destination Point P_d.

3. The anti-swing automatic control system for unmanned overhead cranes of Claim 1, wherein said crane motors (30) comprises the AC motors and the encoders.

4. An anti-swing automatic control system for unmanned overhead cranes comprising;

the velocity profile generator (10) generating position data computed from the predetermined velocity profile when the object is moved from one position to a destination,

the crane motors(30),

the crane motion (70),

the controller (60),

the fuzzy logic controller (40) which senses the angle of swing θ and the angular velocity of swing $\dot{\theta}$ from motion of said crane (70) and compensates the swings utilizing the control algorithm based on the fuzzy rules (402), and

the sensing device (50) which deducts the outputs of the fuzzy logic controller (40) and the position signal P of said crane motors (30) from the outputs of the velocity profile generator (10).

5. The anti-swing automatic control system for unmanned overhead cranes of Claim 4, wherein said velocity profile utilizes the maximum acceleration A_{max} of said overhead crane, the maximum velocity V_{max}, the period of swing T object which is being moved hung on the wire ropes, and the Destination Point P_d.

6. The anti-swing automatic control system for unmanned overhead cranes of Claim 5, wherein if the angle of swing θ becomes 0° when the velocity of the trolley in the acceleration zone B reaches the maximum velocity, the angle of swing θ is maintained at 0° through the maximum velocity (constant velocity) zone C, because angular velocity of swing $\dot{\theta}$ is maintained at 0 throughout the zone.

7. The anti-swing automatic control system for unmanned overhead crane of Claim 5, wherein said fuzzy logic controller (40) comprises a fuzzification interface (401) which measures crisp input values and converts them into fuzzy values; a fuzzy rule (402) to give an effect of minimizing the angle of swing θ; and a defuzzification interface (403) which converts fuzzy output values according to said fuzzy rule (402) into the crisp control output values for actual control.

8. The anti-swing automatic control system for unmanned overhead cranes of Claim 4 or 7, wherein said fuzzy rule 402 is such that;

if the angular velocity is NB and the angle is ZE, then the acceleration of trolley is NB;

if the angular velocity is NM and the angle is ZE, then the acceleration of trolley is NM;

if the angular velocity is NS and the angle is ZE, then the acceleration of trolley is NS;

if the angular velocity is ZE and the angle is ZE, then the acceleration of trolley is ZE;

if the angular velocity is PS and the angle is ZE, then the acceleration of trolley is PS;

if the angular velocity is PM and the angle is ZE, then the acceleration of trolley is PM, and

if the angular velocity is PB and the angle is ZE, then the acceleration of trolley is PB, while NB denotes negative big, NM negative medium, NS negative small, ZE zero, PS positive small, PM positive medium and PB positive big.

9. An anti-swing automatic control system for unmanned overhead cranes comprising a main computer (100), which is a general purpose computer, is equipped with the velocity profile generator (10) or the velocity profile generator (10) together with the fuzzy logic controller (40) ;

a CPU (101) controlling I/O signal ;

the distancemeter (105) via a communication card (102) ;

the crane motor (30) via a D/A converter and counter (103) ;

the motor controller (106), and

the swing angle sensor (109) via an A/D converter (104).

10. The anti-swing automatic control system for unmanned overhead cranes of Claim 9, wherein said distancemeter (105) comprises an X-axis distancemeter (20) and a Y-axis distancemeter (22).

11. The anti-swing automatic control system for unmanned overhead cranes of Claim 9, wherein said I/O ports (103) comprises a D/A converter (103a) and a counter (103b) for counting revolutions of a wheel on a rail, and wherein said crane motor (30) comprises AC motors (107) and encoders (108).

12. The anti-swing automatic control system for unmanned overhead cranes of Claim 11, wherein said AC motors (107) is travelling motors, traversing motors and hoisting motors.

13. An anti-swing automatic control system for unmanned overhead cranes, which system is substantially as hereinbefore described with reference to the accompanying drawings.

Patents Act 1977
Examiner's report to the Comptroller under Section 17
(The Search report)

Application number
GB 9314682.7

Relevant Technical Fields

(i) UK Cl (Ed.L/M) B8H (HGDA) G3N (NGD, NGDA, NGDB, NGE3 - AA, AB, AC, A

(ii) Int Cl (Ed.5) B66C (13/06, 13/22, 13/30, 13/48)

Search Examiner
MR D A SIMPSON

Date of completion of Search
11 OCTOBER 1993

Databases (see below)
(i) UK Patent Office collections of GB, EP, WO and US patent specifications.

(ii) WPI

Documents considered relevant following a search in respect of Claims :-
1-13

Categories of documents

X: Document indicating lack of novelty or of inventive step.

Y: Document indicating lack of inventive step if combined with one or more other documents of the same category.

A: Document indicating technological background and/or state of the art.

P: Document published on or after the declared priority date but before the filing date of the present application.

E: Patent document published on or after, but with priority date earlier than, the filing date of the present application.

&: Member of the same patent family; corresponding document.

Category	Identity of document and relevant passages		Relevant to claim(s)
X	EP 0467783	(CAILLARD) Abstract	1, 2, 3
X	EP 0394147	(REEL S A) Abstract	1, 3
X	US 4717029	(HITACHI) Abstract	1, 3
X	US 4603783	(BETAX) Abstract	1, 3
X	US 4512711	(ASEA) Column 5 lines 30-65	1, 3, 9

Databases: The UK Patent Office database comprises classified collections of GB, EP, WO and US patent specifications as outlined periodically in the Official Journal (Patents). The on-line databases considered for search are also listed periodically in the Official Journal (Patents).