HYDRAULIC ELEVATORS CONTROLLED BY INVERTER

E.Sasaki
Hitachi Ltd., Ibaraki, Japan
Engineer-Elevator Design Dept., Mito-Works

ABSTRACT

In general, speed-control of Hydraulic Elevators is valve system. Hydraulic Elevator is inferior to Traction Elevators, in point of energy consumption and efficiency of operation.
As to the controller, Inverter control system was adopted, in which a new type of control system give good characteristic for Hydraulic Elevator.
This paper describes the outline of Inverter control system for Hydraulic Elevator, saving energy, and improvement efficience of operation.

1. INTRODUCTION

The demand for hydraulic elevators is ever increasing recently. Their number of installation is doubled in these 5 years and shares 20% of all elevators. The hydraulic elevator is driven while the hydraulic jack is bearing the entire load of the car. Therefore, compared with a traction rope type elevator, it requires more power and the hydraulic oil to and from the hydraulic cylinders is supplied and discharged through flow control valves and, thus, the comfortableness changes with the passenger load or oil temperature and other demerits are encountered. Therefore, the operating time shortening or power consumption decrease is desired and improvements (1) by operating time minimizing control system resorting to microcomputers being adopted. As a new type of hydraulic elevator, one whose electric motor speed is varied for car speed control (2) is being developed.
This time, we pursued a development of a hydraulic elevator with inverter control system whose electric motor speed is controlled through an inverter control unit adopted by a traction rope type elevator. The paper reports result the study for reducing the power consumption and operating time.

2. OVERALL CONFIGURATION OF INVERTER CONTROLLED HYDRAULIC ELEVATOR

Fig. 1 shows the overall configuration. The car is subjected via a rope to 1:2 roping, raised by hydraulic oil sent to the hydraulic jack and, at downward running, oil is discharged from the hydraulic jack to the tank. The motor speed is controlled by a voltage type inverter through speed feedback from the encoder and an oil flow proportional to the speed of a reversible hydraulic pump is sent to the hydraulic jack via the control valve or discharged to the tank. The inverter unit is a vector controlled voltage type inverter adopted for the traction rope type elevator. The control valve is provided with check valve which holds the pressure in the hydraulic jack, safety valve which operates if the hydraulic pump delivery pressure has risen and suction valve which prevents a depression between the hydraulic pump and check valve from causing a pump cavitation.

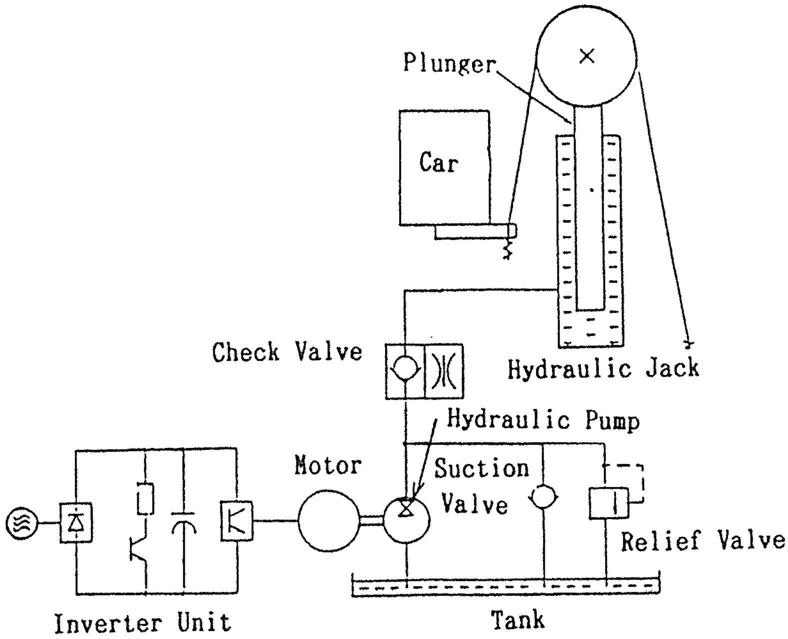


Fig.1 Hydraulic Elevator system

When the elevator runs upward, the inverter control unit increases the frequency continuously to rotate the hydraulic pump. Hydraulic oil delivered from the hydraulic pump passes without bleed-off through the check valve and is sent to the hydraulic jack. When the rated speed is attained, the hydraulic pump operates at a constant speed. When a deceleration command is delivered, the inverter unit gradually decreases the frequency and, while decreasing the hydraulic pump speed, elevator decelerates and stops at level. During downward running, the hydraulic pump is rotated in the direction opposite to that of upward running with the check valve opened, thereby returning hydraulic oil from the jack to the tank.

3. STUDYING POWER CONSUMPTION

3.1 Flow of Energy of Hydraulic Elevator

Fig. 2 shows the flow of energy from the inverter control unit to the car. From the inverter control unit to the motor, voltage and current are given as electrical energies. The electric motor changes the electrical energy into a rotational energy (speed of revolution, torque), which is transmitted to the pump. The pump sends hydraulic oil having certain pressure and flow rate to the hydraulic jack, which transmits a mechanical energy via the rope to the car. It is clear that there is an almost proportional relationship between these energies as expressed by:

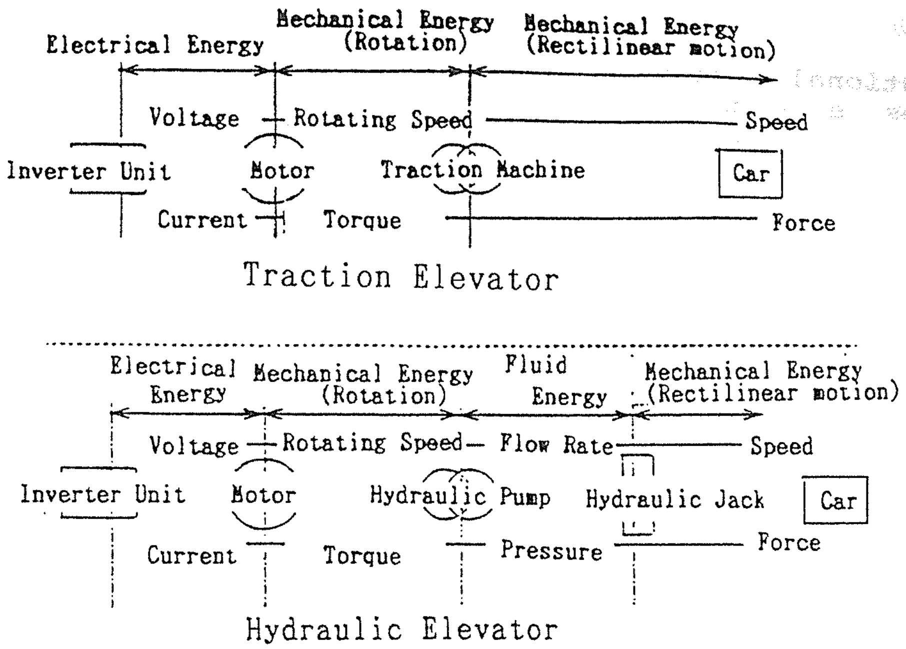


Fig.2 Flow of Energy

Voltage V (frequency) $\propto$ Speed of revolution N $\propto$ Flow rate Q $\propto$ Speed v

Current i $\propto$ Torque T $\propto$ Pressure P $\propto$ Force F

Therefore, the factors of flow rate and pressure are also proportional to the speed of revolution and torque. Thus, the power consumption can be considered with a concept of torque and speed of revolution the same as the traction rope type elevator.
Suppose the elevator speed is v, the delivery rate Va per rad/s of pump, the pump speed of revolution N, and the sectional area of plunger S, 1:2 roping gives:

$$v = 2 \cdot Q/S \quad (1)$$
$$Q = Va \cdot \dot{\theta} \quad (2)$$

Supposing the pump delivery pressure is Pp, the angular speed of pump θ, and the coupling inertia efficiency J for motor, pump and coupling, and ignoring the viscosity resistance, motor torque Tm is:

$$Tm = J \cdot \ddot{\theta} + Va \cdot Pp \quad (3)$$

Therefore, suppose the pump efficiency is ηp, power Pow is,

$$Pow = 2\pi N \cdot Tm/60/\eta p \quad (4)$$

3.2 Results of Study

Calculated results are given in Fig. 3 and 4. Fig. 3 shows the elevator speed, power consumption and motor current when inverter control. When controlled by the inverter, the speed is continuously changed during acceleration or deceleration and, as shown by expression (4), the power consumption is proportional to speed N and, therefore, the waveform is similar to the elevator speed characteristics. Fig. 4 shows a simulation of a case with a conventional hydraulic elevator. From start to stop, the motor rotates at a constant speed and, therefore, the motor current is almost constant from acceleration to stoppage. The power consumption is proportional to the current and is greater than that of inverter control. Their comparison reveals that an adoption of inverter control system saves approximately 30% of energy.

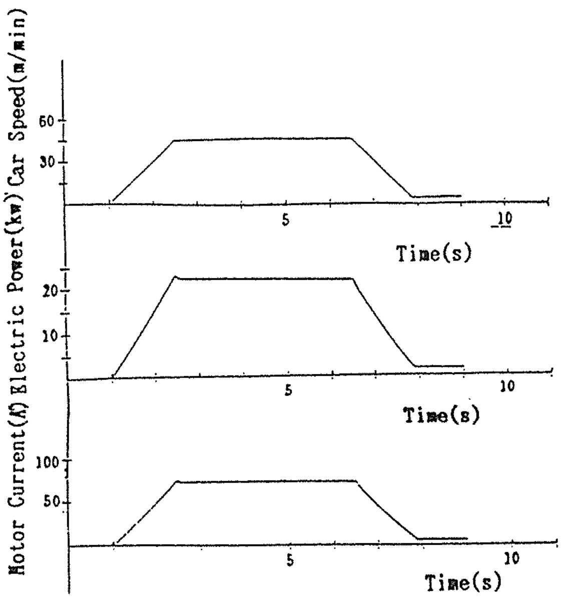


Fig.3 Energy Consumption by Inverte Control System (Simulation)

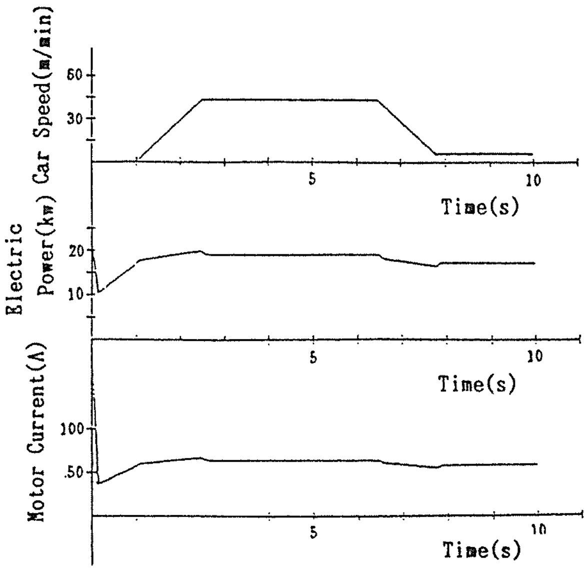


Fig.4 Energy Consumption by Valve Control System (Simulation)

Fig. 5 and 6 show the elevator speed, source current and power consumption on an actual elevator. The elevator stroke is 4 m and the car speed is 45 m/min. The characteristics are the same as calculated and the power consumption is 25% smaller with the inverter control system than the conventional one.

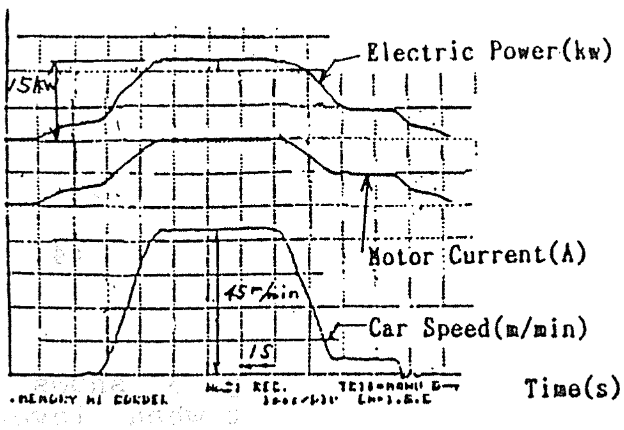


Fig.5 Energy Consumption by Inverter Control System

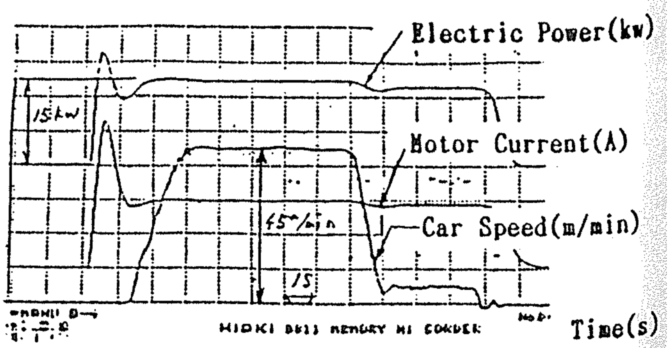


Fig.6 Energy Consumption by Valve Control System

4. SHORTENING THE RUNNING TIME

Fig. 7 shows the running characteristics during upward running at a car speed of 45 m/min. In the conventional system, the landing takes approximately 2 seconds after end of deceleration. With the inverter control, it is reduced to 1 second through a speed feedback and the running time is also decreased by 10%.

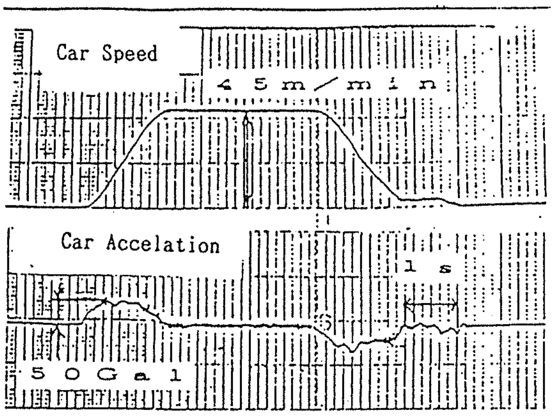


Fig.7 Characteristics of Upwards Running

5. CONTROL VALVE FUNCTIONS, STRUCTURE AND CONTROL METHOD

5.1 Functions and Structure

The functions of control valves are as follows.
1) Hold the car position securely when it is stopped
2) Ensure safety during power failure
3) Avoid over-speed
4) Reduce motor power during upward running
5) Protect the hydraulic circuit
6) Warm up when oil temperature is low

Fig. 8 shows the hydraulic circuit, Fig. 9 and 10 the structure, and Fig. 11 the control sequence during downward running. The control valves are divided into downward control valve covering 1) to 4) above and relief unloading valve covering 5) and 6).

For the downward control valve, poppet type main valve, operating piston and 3 electromagnetic pilot control valves (hereinafter referred to as pilot valve) constitute a pilot operated check valve. Therefore, the flow from the pump to the jack is allowed and the

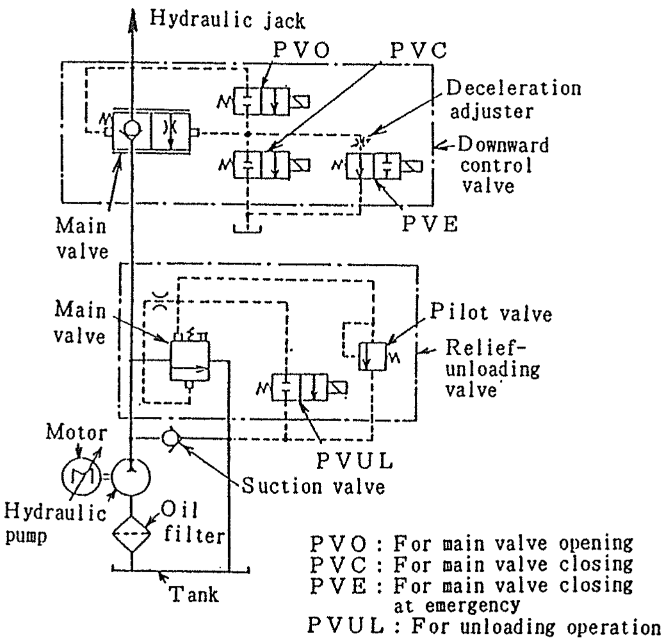


Fig. 8 Schematic diagram of hydraulic circuit

reverse flow is blocked normally. During upward running, it operates as a simple check valve and, according to the flow rate, the main valve opens. Thus, it closes automatically during power failure or other emergency cases. This arrangement stops the car safely without over-speed. During downward running, on the other hand, the pilot valve is energized and, by operating the piston, the main valve is opened to a certain degree. Pilot valves PVO, PVC and PVE operate as follows. PVO is a pilot valve which opens the main valve. Normally, it blocks the piston chamber and jack port. When energized, it supplies a jack port pressure to the piston chamber. PVC is a pilot valve which opens the main valve. Normally, it blocks the piston chamber and tank. When energized, it releases the pilot pressure of piston chamber to the tank. PVE is a pilot valve which closes the valve during power failure or other emergency cases. Normally, the pilot pressure of piston chamber is released to the tank via the metering orifice shown in Fig. 10. When energized, it blocks the piston chamber and tank. During downward running, the above pilot valves are energized as shown in Fig. 11 to open or close the main valve. If the main valve is not closed during power failure or other emergency cases during downward running, the car might drop while increasing its speed by its own weight. Therefore, stopping the car safely while avoiding an over-speed is an important

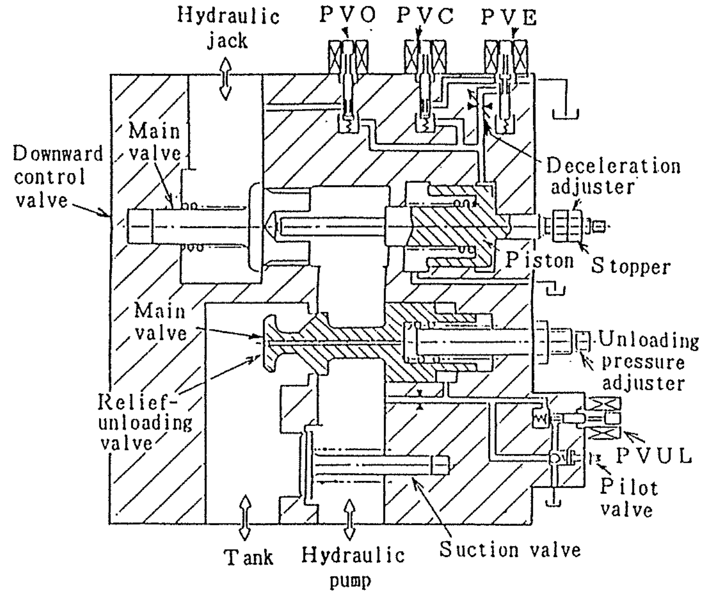
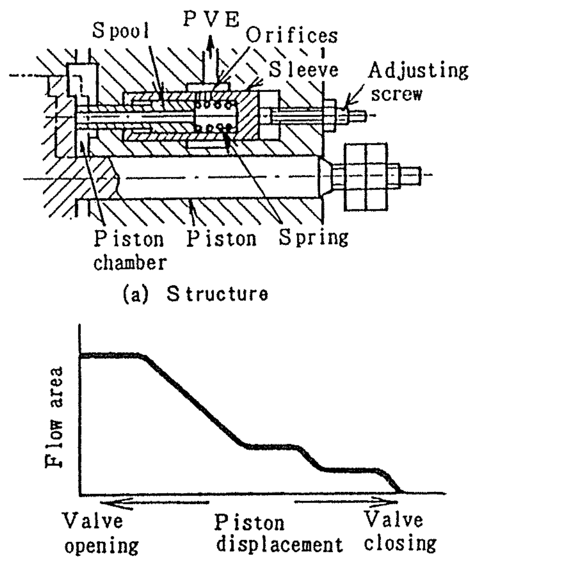


Fig. 9 Schematic structure of control valve



(a) Structure

(b) Relation between piston displacement and flow area

Fig. 10 Detail of deceleration adjuster

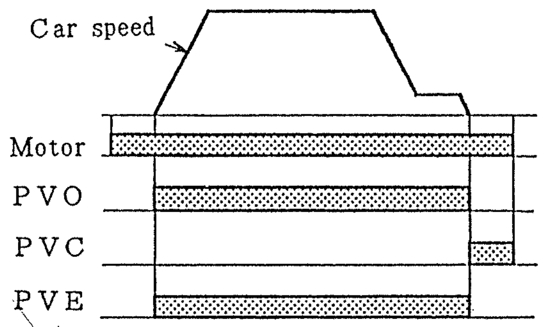


Fig. 11 Sequence diagram of downwards running

function of safety. On the control valve, the over-speed is avoided by providing an appropriate opening area of main valve (setting the operating range of piston by an adjustable stopper) and, for car stopping, the above pilot circuit which closes the main valve automatically is adopted. In case of power failure or other emergency cases, pilot valves PVO and PVE are de-energized (PVC is not energized) and the pilot pressure in the piston chamber is released from the metering orifice via PVE to close the main valve. At this time, the valve closing rate is adjusted by the metering orifice and, therefore, the car is decelerated and stopped safely with a short stopping distance.

The relief unloading valve is a pilot operated type. Energizing pilot valve PVUL releases the pilot pressure to the tank to work as an unloading valve. When the oil temperature is low, it works for warm-up. The unload pressure is controlled by an adjusting screw.

The suction valve is a check valve. It supplies hydraulic oil to the pump so as to avoid a cavitation when a negative pressure occurs between the pump and downward control valve.

5.2 Force Exerted to Downward Control Valve during Downward Running

Fig. 12 shows a downward control valve during downward running. Static valve opening force F acting on the main valve is expressed by:

$$F = (S_{vm} - S_{p1})P_p + (S_{p2} - S_{vm})P_1 - F_{a1} - F_{a2} - F_1 \quad (5)$$

where, S_{vm} : pressure receiving area of main valve
S_{p1} : pressure receiving area of piston rod
S_{p2} : pressure receiving area of piston
P_p : pump port pressure
P_1 : jack port pressure
F_{a1} : spring force of main valve
F_{a2} : spring force of piston
F_1 : fluid force

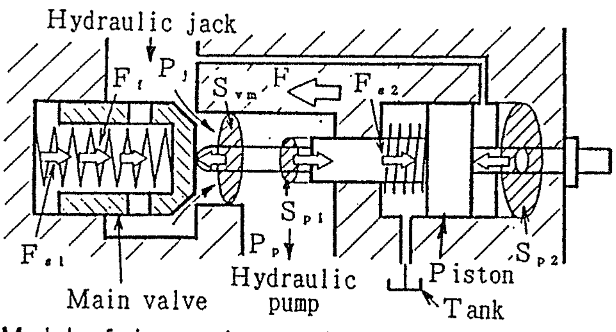


Fig.12 Model of downward control valve at downwards running

Therefore, each parameter has been studied and the main valve operating force and opening degree have been determined to maintain the valve opening securely at a rated speed, stop the car safely during power failure or other emergency cases and limit the speed when it tends to be excessive.

Fig. 13 exemplifies emergency stop characteristics when the motor drive force is lost after power failure during downward running.

At this time, the control power is de-energized and, therefore, each pilot valve is also de-energized. And the pilot pressure of downward control valve is released through the metering orifice to the tank. Thus, the main valve transfers to a gentle closing operation midway during closing until it closes completely. In this way, the car stops quickly and without excessive shock and safe stopping characteristics are obtained.

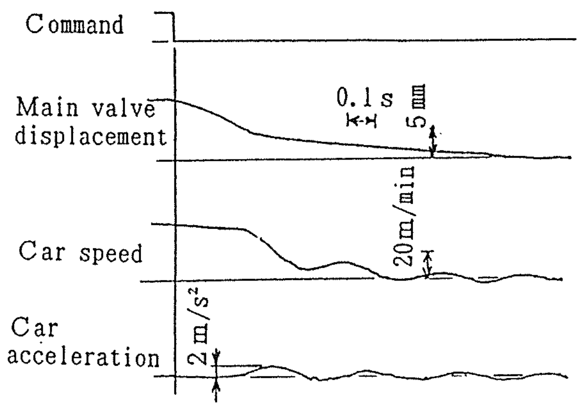


Fig. 13 Characterisitics of emergency stop at downwards running

6. CONCLUSION

We studied how to reduce the power consumption and running time when controlling the hydraulic pump of a hydraulic elevator by an inverter and,

(1) Checked the power consumption at an elevator operation by a simulation and on an actual elevator and confirmed 25% of reduction.

(2) When raising 4 m of stroke, the time decreased from 10 seconds for conventional type to 9 seconds, representing 10% of reduction.

7. REFERENCES

(1) Takeda, et al.: Development of High-Reliability Power-Saving Hydraulic Elevators, Hitachi Review 70, 10 (December, 1988)

(2) Miyazawa, et al.: Development of Induction Motor-Driven Variable-Speed Hydraulic Elevators, Japan Machinery Institute, (No. 900-44), Anthology of Lectures of Dynamics (Vol. B) (July 12-14, 1990)

(3) Nakamura, et al.: Study of Speed Control of Hydraulic Elevators, Lectures at Local Meeting of Hitachi, 130/132 (September, 1988)

(4) Yamamoto, et al.: Electro-Hydraulic Elevators, Technical Report of Mitsubishi Electric, 61-11, 851/854 (1987)

(5) Hatano, et al.: New Control Hydraulic Elevators, Mechanism, No. 910-3, 59/62 (January, 1991)

(6) Fukunaga, et al.: Development of Electronic Controlled Hydraulic Elevator Valves, Technical Report of Kawasaki Heavy Industries, 108, 44/50 (January, 1991)

(7) Miyazawa, et al.: Development of Induction Motor Variable-Speed Hydraulic Elevators, Mechanism, No. 900-44, Vol. B, 72/75 (July, 1990)

(8) Sasaki, et al.: Inverter Control Hydraulic Elevators, Mechanism, No. 910-3, 52/54 (January, 1991)