# Development Of Elevator For Personal House

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## Abstract

Our living environment is now being built to enrich the welfare of old persons with due consideration. We have developed a new elevator for personal houses based on this social demand. We have succeeded in noticeably compacting the control circuits and reducing electromagnetic noises at a higher switching frequency by utilizing a reduced instruction set computer and insulated gate bipolar transistors. We have simplified our control system by integrating its power supply for control circuits to have successfully installed the control panel in the hoistway.

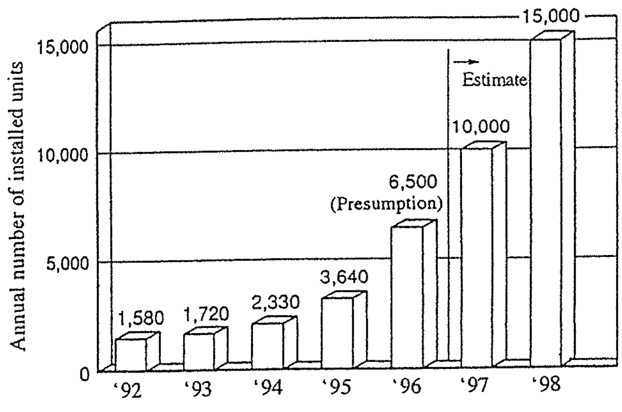
## 1. Introduction

One out of four persons in the total population is estimated to be 65 years or older in 2020 AD. As the advanced age-oriented society progresses, the life style is being changed from the nuclear family to the extended family sharing the same house with two households and three generations, and three-storied and four-storied houses are increasing for the purpose of utilizing the land and space effectively.

In these multistoried houses, ascending and descending the stairs is a strain on aged persons, and it causes a dangerous accident. As the dwelling environment changes, the installation of a home elevator being kind to these aged persons is being demanded. In recent years, its demand is being expanded more than 50% in annual ratio. (See Fig. 1.)

This abrupt market expansion is mainly caused by a gradual change of houses from high-grade houses showing a status symbolic factor to popular houses due to low prices and the sales of houses being equipped with a home elevator as a new commodity having a new added value by big house makers to meet the creation of the advanced age-oriented society.

We have developed a low-priced and space-saving home elevator "Home Ace Lifting Mood" to conform to such a change of the house market, and then, put it on sale in January 1997.




The number of installed home elevators in 1996 amounts to about 4 times as compared with it in 1992 due to the arrival of the advanced age-oriented society, an increase of 3-storied houses, reduction of prices, house makers' standard equipment design and propagation effects, and other circumstances.

Fig. 1 Transition of the number of installed home elevators

# 2. Specifications and entire structure of elevator

## 2.1 Specifications

Table 1 shows the specifications of "Home Ace Lifting Mood". Its major features lie in the fact that two types (type 1 and type 2) of specifications are prepared and option functions in conventional models are assembled as standard specification functions to enable users to purchase them easier. In addition, it provides various functions to be ready against service power interruption, earthquakes, and other emergencies.

Table 1 Specifications of "Home Ace Lifting Mood"

In type 2, the automatic landing device in the occurrence of service power interruption, wooden handrails, and other options are included in the basic specifications to enable users to purchase the elevator easier.

| Items | Type 1 | Type 2 |
|---|---|---|
| Use | For individual houses | |
| Load | 200kg | |
| Number of fixed passengers | 3 persons | |
| Speed | 12m/min | |
| Stop position | Max. 4 positions | |
| Drive system | Basement hoisting drum system | |
| Control system | Inverter control system | |
| Door drive system | Electric two speed door (with a safety shoe) | |
| Dimensions of cage room | 900mm (frontage)×1,200mm (depth)×2,000mm (height) | |
| Dimensions of entrance | 800mm (width)×1,900mm (height) | |
| Power supply | Single-phase 3-wire system 200V | |
| Motor capacity | 1.5kW | |
| Support structure | Half self-standing type (also serves as the rail) | |
| Handrail base | ○ | ○ |
| Standing lamp | ○ | ○ |
| Automatic landing device in the occurrence of service power interruption | △ | ○ |
| Wooden handrail | △ | ○ |
| Operation for earthquake | △ | △ |
| Two-way entrance of cage | △ | △ |

Note: Description of symbols ○(Basic specifications), △(Option)

## 2.2 Entire structure

Fig. 2 shows the entire structure of elevator, and Fig. 3 shows the plan of the hoistway.

The pit base is fixed at the hoistway pit, and two right and left guide rails are erected on this base. A pulley beam being assembled with a guide pulley is mounted above the guide rail. A traction machine is mounted at the lower part inside the hoistway. This traction machine is designed as the drum type to simplify the hoisting structure.

A control panel is mounted above the traction machine so that a person can face the accent panel (inspection cover) on the wall face of the car when the car stops on the bottom floor. As a result, the conventional inspection door was removed from the door pocket of the landing to have enhanced the freedom to finish the landing side wall as the design activity.

The guide rail made of a steel plate is arranged on the landing side of the hoistway. By mounting the entrance frame and other units from this guide rail, the clearance between the landing sill and the car sill can be secured accurately.

Owing to these features, all loads in the vertical direction on the elevator side are supported by the pit via the guide rail. The horizontal loads caused by earthquakes, etc., are supported by the building via the mounting parts connected to the guide rail and the building landing side beam as the "semi self-standing iron tower structure". This half self-standing iron tower structure facilitates the application of the elevator to wooden and light weight steel construction houses.

The internal area of the hoistway of approx. 2.2m$^2$ has realized space-saving. In addition, the working period has been reduced to shorten necessary delivery period by (1) 3-division FRP (glass-fiber reinforced plastic) design of the right and left walls and ceiling of the car, (2) reduction of the number of mounting parts as a result of the pre-fabricated system of devices and units, and (3) the simplified installation, centering, and adjustment by a new installation work method to the fixing of the landing side rail.

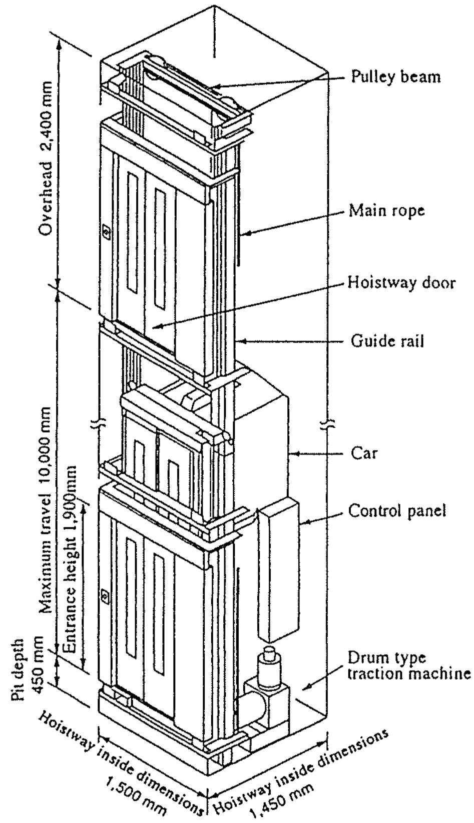



Fig. 2 Entire structure

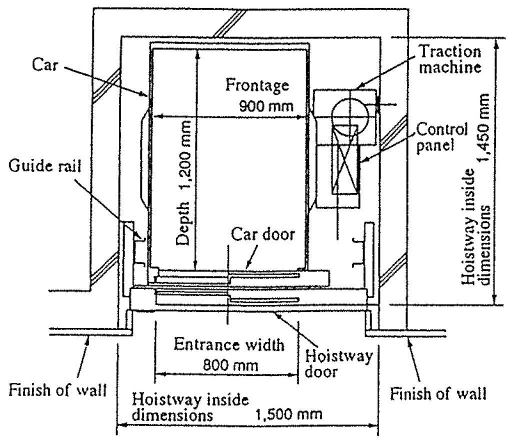



Fig.3 Plan of hoistway

## 3. System configuration

### 3.1 Entire system configuration

Fig. 4 shows the entire system configuration of Home Ace.

The main circuit assembly of Home Ace is composed mainly of the full-wave rectification converter for single-phase power supply, the inverter to feed 3-phase AC power to the induction motor, and the filter capacitors to smoothen the DC voltage, while the microcomputer assembly is composed of the three-microcomputer system where the running and position control processing is executed by master and slave microcomputers (16-bit microcomputers) while the processing of the automatic speed regulator (ASR) including the vector control system, automatic current regulator (ACR), and pulse width modulation (PWM) controller is collectively executed by the 32-bit reduced instruction set computer (RISC) (hereinafter referred to as inverter microcomputer).

Input/output and safety relays for general signals inside the car and hoistway for call from car, call from elevator hall, etc., and inverter power feed contactor are driven by master microcomputer, while safety relays and brake relays are driven by the slave microcomputer. Important signals of gate switches, limit switches, and positectors inside the car and hoistway are doubly input through the general-purpose port in the master and slave microcomputers. Also, an IPM (Intelligent Power Module) drive signal is prepared by the inverter microcomputer, and main circuit protective signals are input to the inverter microcomputer and transmitted to the slave microcomputer to secure high safety by means of the suppression from both microcomputers.

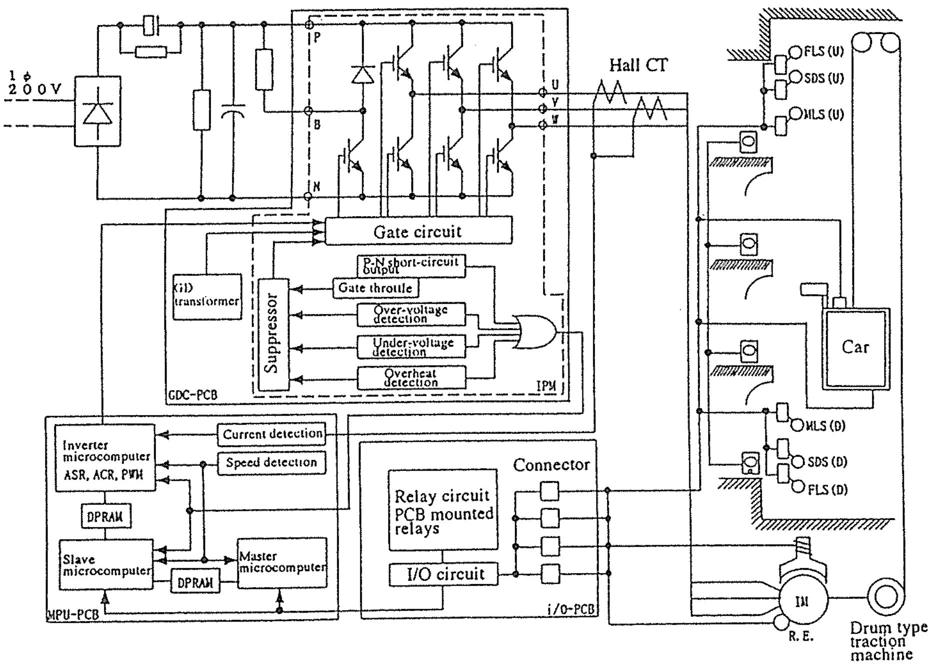



Fig. 4 Home Ace system configuration

### 3.2 Inverter control

Fig. 5 shows the control block diagram of inverter microcomputer. Home Ace adopts the inverter microcomputer and the total digital control system which digitally processes from the velocity command input to the PWM pulse output. The inverter microcomputer processing for realizing the fully digital control will be described referring to Fig. 5.

(1) ASR unit

The ASR unit receives the velocity command $\omega^*$ prepared by the slave microcomputer and calculates the velocity deviation by obtaining a differential from the velocity feedback from R.E. (Rotary Encoder). It calculates the proportional plus integral control to the above velocity deviation to calculate torque command $\tau^*$. This torque command $\tau^*$ shows the percentage to the rated torque of motor, and current command $I_q^*$ (torque current component) and slip frequency $\omega_s^*$ are calculated from this torque command. Primary frequency command $\omega_1^*$ is obtained by adding velocity feedback $\omega_r$ to this slip frequency $\omega_s^*$. These two variable $I_q^*$ and $\omega_1^*$ and fixed value $I_d^*$ (exciting current component) serve as the command values to ACR unit.
This ASR unit executes these calculation at 2ms intervals.

(2) ACR unit

ACR unit inputs primary frequency command $\omega_1*$, current commands $I_q*$, $I_d*$ prepared in ASR and 2-phase/3-phase converted values from hall CT $I_u$, $I_v$ into the non-interference DC.ACR operation block. ACR unit executes 2-phase/3-phase conversion of the voltage commands $V_q*$, $V_d*$ calculated by the operation block and the phase angle $\theta_d*$ prepared by multiplying primary frequency command $\omega_1*$ by time gain. On the other hand, current commands $I_q*$, $I_d*$ prepared in ASR are 2-phase/3-phase converted and input into the AC.ACR operation block for calculation. Voltage commands $V_u*$, $V_v*$, $V_w*$ are calculated by adding both operation results. These voltage commands are line-voltage-modulated to prepare PWM pulse signals.
ACR unit executes the above arithmetic operation at 100$\mu$s intervals.

(3) PWM control unit

The PWM pulse generator unit generates pulses from the voltage command and outputs a pulse signal to the gate drive PCB to drive the IPM gate.

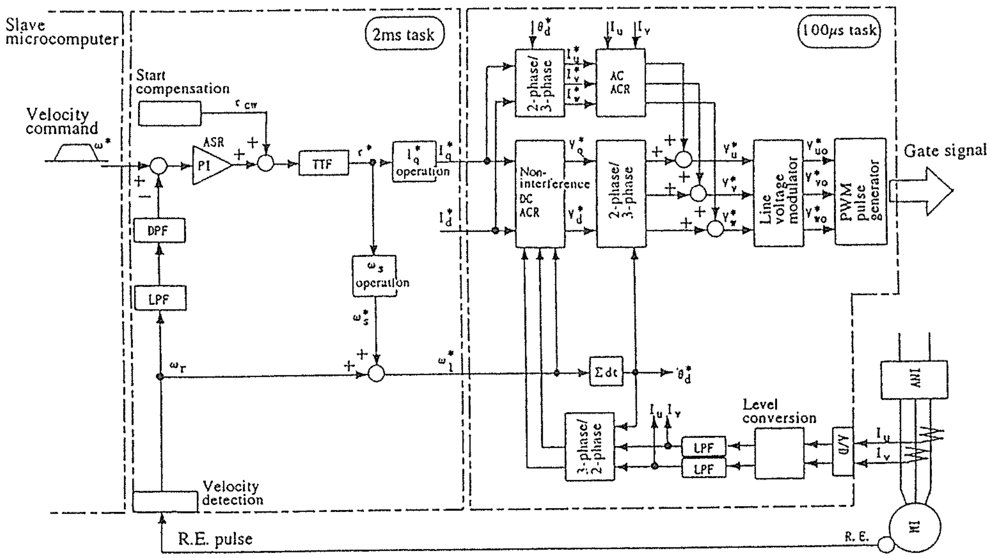



Fig. 5 Inverter control block diagram

### 3.3 Inverter main circuit

Home Ace adopts an IPM as the drive device. This IPM is an IGBT (Insulated Gate Bipolar Transistor) device having a self-protective function to automatically shut off a current by detecting an over-current, short-circuit, under-control voltage, overheat of devices, etc. by it self.
This IGBT also serves as a voltage drive type device to be able to execute high-speed switching of 10kHz or more, so that the noise level can be reduced by setting the switching frequency to be high without using any RC (Reactor Capacitor) filter for low noise band.
IPM devices are connected to each other compactly and the snubber circuit is constructed as a module to be mounted on GDC-PCB (Printed Circuit Board) which comprises the control power circuit and drive circuit on board to be directly mounted to IPM. As a result, the main circuit is simplified as a wiring-free unit. If IPM is abnormal, emergency processing is done according to its error signal to simplify the main circuit protective device.

### 3:4 Power supply circuit

The voltage to be supplied to the control circuit is integrated to DC 48V and DC 22V by rechecking and integrating the system power line. DC 48V is applied to the brake drive circuit and door control circuit, and also, DC 22V is applied to the indicator circuit using LED (Light Emitting Diode). In addition, an AVR (Automatic Voltage Regulator) for control power supply is mounted on the I/O printed circuit board (hereinafter referred to as I/O-PCB) as a regulator (DC-DC converter) to have simplified the circuit structure.
Fig. 6 shows the Home Ace power supply block diagram.

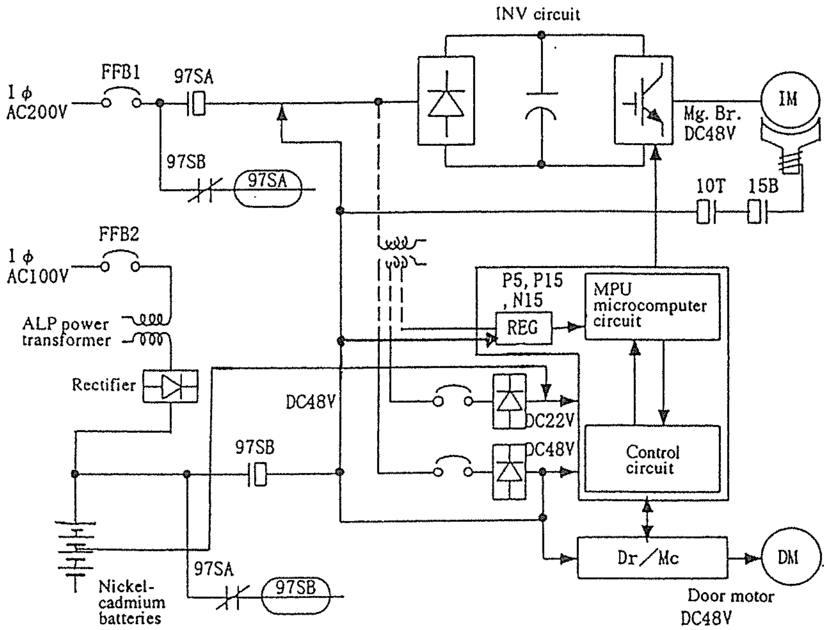



Fig. 6 Power supply block diagram

### 3.5 Control panel structure

In order to satisfy the space-saving of the hoistway, the control panel size was rechecked. The depth size was suppressed in particular to have reduced the mounting space of the control panel. Fig. 7 shows the control panel structure.
The control panel is designed to be compact by the following methods.
(1) Internal wiring of the panel was reduced by directly connecting the intra-hoistway wiring, traveling cable, and other cables from the outside of control panel to the I/O-PCB by means of connectors.
(2) In order to simplify the main circuit as a wiring-free unit, the control power circuit, drive circuit, and snubber module are assembled on a board and directly mounted to IPM.
(3) Power supplies are integrated by rechecking the power supply circuit and an AVR is assembled on I/O-PCB.

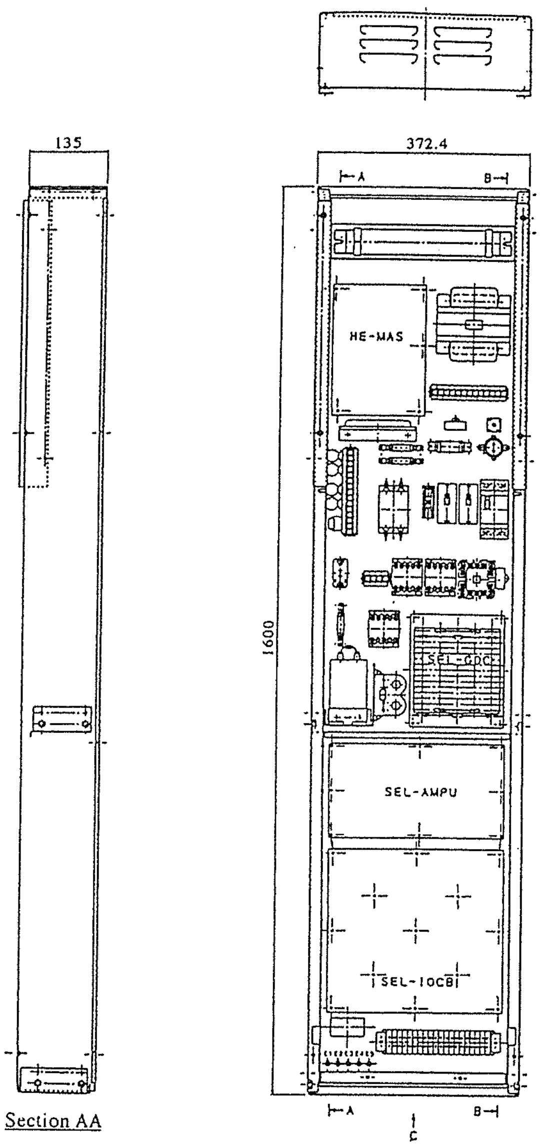



Fig. 7 Control panel structure

## 4. Review of safety

### 4.1 Safety of system

Since Home Ace is often mounted in wooden storied houses, unlike in general elevators, the security against a fire becomes severe. Accordingly, an intra-panel devices protective cooperation function and an overheat detection function are provided inside the power transformer coils with due consideration.

The microcomputer system is constructed to execute mutual monitoring between master and slave microcomputers, mutual monitoring between inverter microcomputer and slave microcomputer, and a double input of important signals to have simplified the microcomputer peripheral circuit with improved reliability and safety. If the inverter microcomputer is abnormal, IPM is directly suppressed from the slave microcomputer without being through the inverter microcomputer to have secured the safety of the elevator system.

If an over-voltage or under-voltage failure of the inverter main circuit occurs, the circuit mounted in GDC-PCB detects such a failure to directly suppress IPM and the inverter microcomputer receives this signal to shut off the gate signal to have secured the safety.

The IPM being adopted in the inverter main circuit is provided with a built-in trouble detection circuit against an over-current, overheat, and other abnormal symptoms, and it provides a self-shut off function of current when a trouble occurred. When IPM is shut off by the protective operation in the occurrence of a short-circuit failure, the IPM gate voltage is reduced to an intermediate voltage once so as to reduce the generation of a surge voltage caused by the shut-off operation of IPM to have improved the main circuit protective function.

### 4.2 Reduction of confinement

Home elevators are presumable to increase rapidly in the future. However, since they are mounted in individual houses, the confinement trouble must be prevented as much as possible. Fig. 8 shows the confinement rescue operation flow chart in Home Ace. The ALP (Automatic Landing Device for Power Failure) is mounted as the standard equipment to reduce the confinement due to a service power interruption which is presumable to increase hereafter. Home Ace ALP can be utilized by aged persons, wheeled chair users, and children owing to its automatic landing by inverter control and automatic door opening function by door control. This ALP may be the most effective when an increase of the mounting units of small elevators for individual houses and quick remedial measures against a wide area service power interruption are taken into consideration.

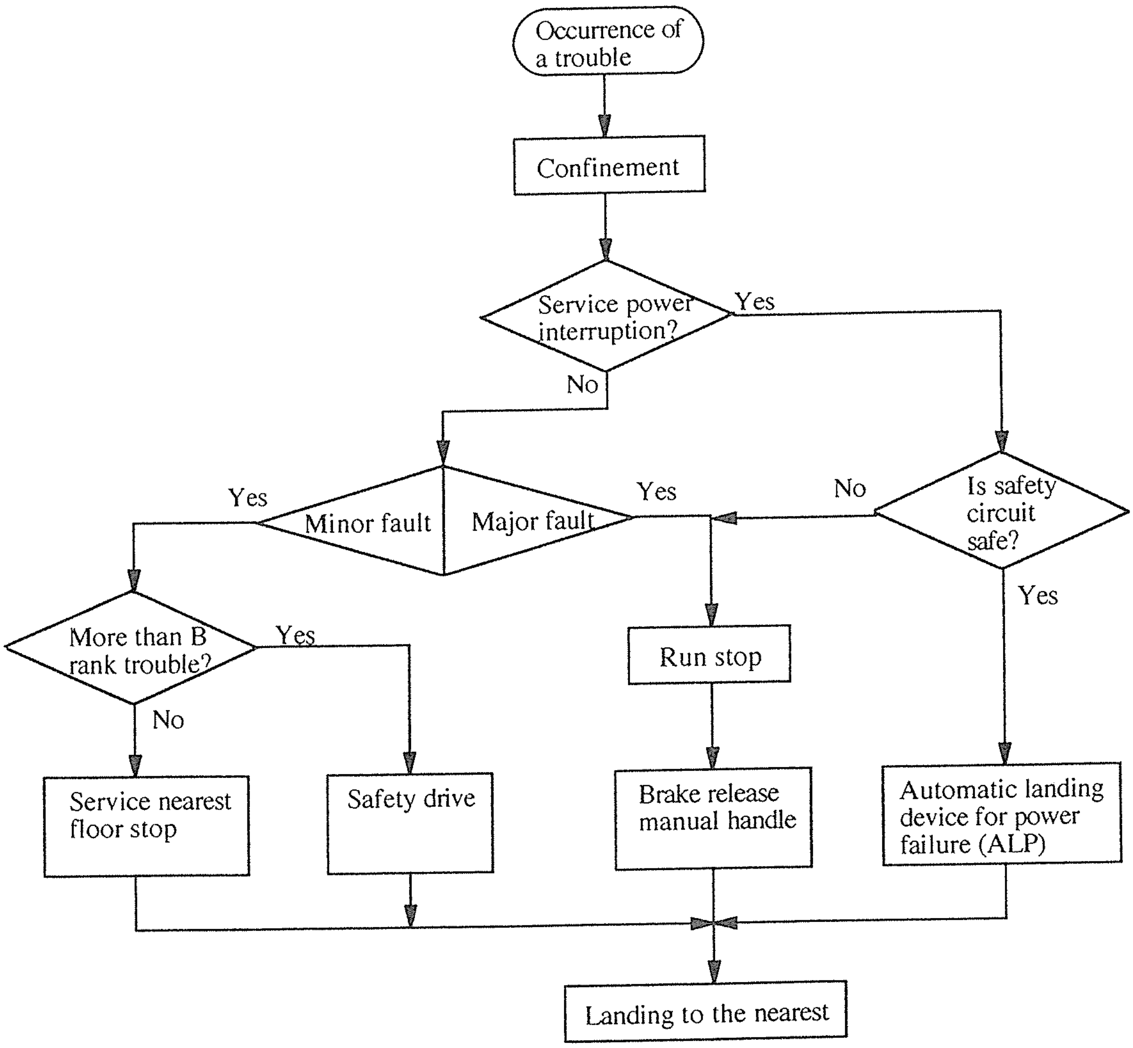
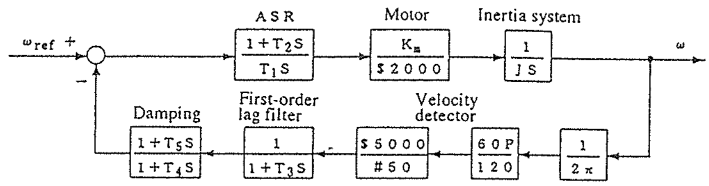



Fig. 8 Rescue operation flow chart in the occurrence of a confinement failure

# 5. Test results

## 5.1 Traveling performance

Fig. 9 shows the Home Ace ASR system block diagram and Fig. 10 shows the open loop board diagram. The sampling cycle of ASR system is 2ms as described before. Since a small motor having an output of 1.5kW is used, the rated slip frequency increases as compared with general elevators. Accordingly, integral gain $T_1$, proportional gain $T_2$, first-order lag filter constant $T_3$, and damping constants $T_4$, $T_5$ were designed so that the cross-over angle frequency becomes 40rad/s. Fig. 11 shows its running waveform. This figure shows good running waveforms where the start-deceleration shock is 30gal or less and undulating vibrations are 20gal or less during rated speed operation.




where,
$T_1$ (Integral gain) = 0.512
$T_2$ (Proportional gain) = 0.636
$K_m$ (Rated torque of motor) = 10.1 (Nm)
J (Motor shaft conversion inertia efficiency) = 0.007 ($kgm^2$)
$T_1$ (No. of motor poles) = 4
$T_3$ (First-order lag time constant) = 0.008
$T_4$ (Damping constant) = 0.025
$T_5$ (Damping constant) = 0.040

Fig. 9 ASR system block diagram

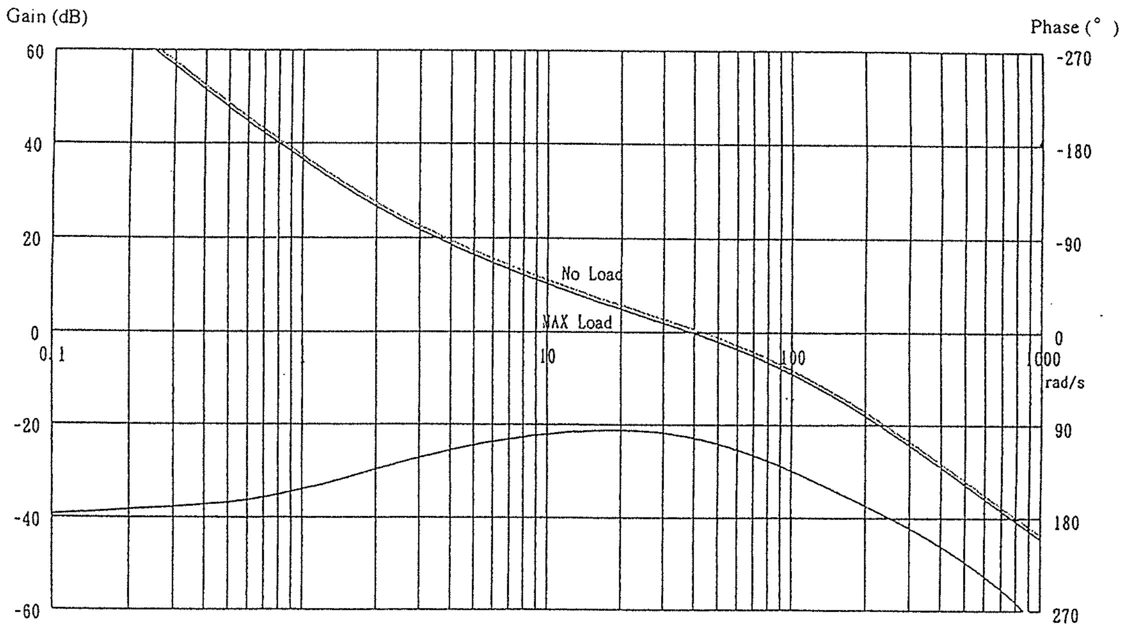
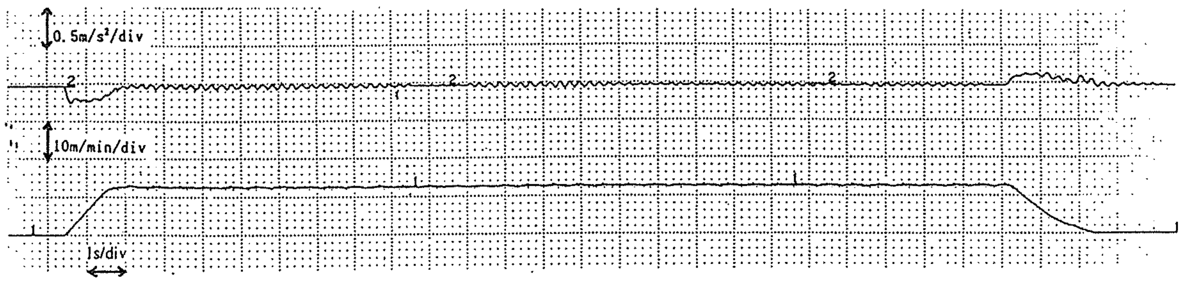



Fig. 10 ASR open loop board diagram


(a) Running waveform during full load up run




(b) Running waveform during full load down run

Motor rating : Output 1.5kW
Voltage 170V
Frequency 50Hz
Rated speed 1436rpm
Rated current 7.92A
Load : 200kg

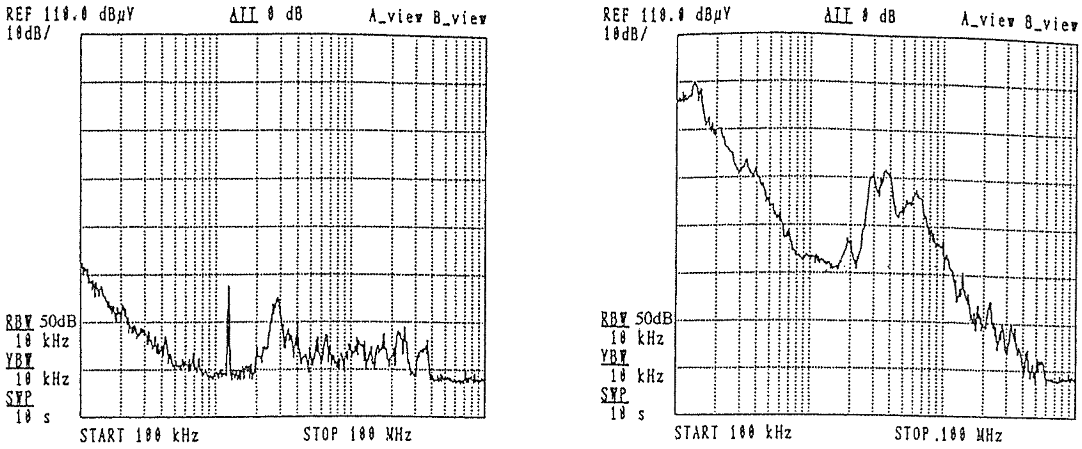
Fig. 11 Running waveforms

## 5.2 Higher harmonic wave

By adopting IPM, the high-speed switching is possible to have reduced the inverter noises. As a result, intra-car noises were reduced to be 55dB (A) or less and noises at the front of hall were reduced to be 50dB (A) or less during the full load lifting of elevator without mounting any RC filter for electromagnetic noises.

On the other hand, high-frequency noises increase, and electromagnetic noises are anticipated in a radio frequency band of 500kHz～10MHz, in particular.

Accordingly, a power noise filter is mounted as the standard specification for the purpose of suppressing the flow-out of electromagnetic noises. Fig. 12 shows the evaluation results.




(a) During elevator stop (peak value)

(b) Full load up run (peak value)

Fig. 12 Main terminal interference voltage

Fig. 12 shows the measuring results of the main terminal interference voltage for evaluating the high-frequency conductive electromagnetic interference which is transmitted through the power line conductors. The peak noise terminal voltage was suppressed to be about 80dB (0dB=1$\mu$V) or less over a frequency range of 500kHz～10MHz during full load up run as shown in Fig. 12.

## 6. Conclusion

In order to reinforce the sales points and expand the share of home elevators, the control unit has been newly developed to have obtained the following conclusion.

(1) The IPM system of inverter main circuit and fully digital current control system including PWM circuit have been realized. As a result, the main circuit is designed to be compact.

(2) The power supply circuit is integrated and also simplified by assembling its AVR on a board.

(3) Low noises have been realized by high-speed switching by means of IGBT employed as an inverter main circuit device. A noise filter is used to suppress the flow-out of high-order higher harmonics.

(4) By the above design, the control panel is designed to be compact and mount able in the hoistway.