The Latest Drive Technology for Elevators

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ABSTRACT

A drive control system is one of the fundamental elements to constitute an elevator in that its motive power will govern the basic function of elevator's ability to transport passengers vertically and comfortably. In this regard, much attention has been paid to the performance of the drive control system by both customers and manufacturers. This drive technology developed rapidly with the introduction of inverter control. In this paper, we will describe the latest drive technology for traction and hydraulic elevators focusing on inverter control.

1 INTRODUCTION

It has been approximately 100 years since modern-style elevators equipped with safety devices have been brought to the real world. Elevators are not merely a means of transportation but convenience, comfort, and energy saving are demanded.

We, at Mitsubishi Electric Corp., introduced the world's first high speed elevators with inverter drive control in 1983, then adapted this method to drive low speed elevators in 1984, making Mitsubishi Electric the world leader in elevator drive control.

As a result of these advances, inverter control is the main driving control method for low and high-speed traction type elevators. Recently, Mitsubishi Electric once again improved the inverter control applied to traction type elevators and introduced the inverter control method into the driving of hydraulic elevators. In this paper, these latest drive control technologies for elevators are described.

2 HISTORY OF DRIVING CONTROL IN ELEVATOR

Table 1 shows the history of our recent driving control system. In this table, elevators are assorted into traction type elevators and hydraulic elevators by differences in the medium of power transmission. Traction type elevators are furthermore classified, for convenience, by ranges of the rated speed into high-speed elevators of not less than 120m/min(400fpm) and low-speed elevators of 30m/min(100fpm) to 105m/min(350fpm). For high-speed elevators, the Thyristor-Leonard control had been the most popular system because of the advantage of an easy torque control in combination with a DC motor and superiority in power consumption over the Ward-Leonard control. For low-speed elevators, the primary voltage control of an induction motor had been the most commonly applied.

Table 1 History of elevator driving control system

TYPE	CAR SPEED	CONTROL SYSTEMS	
TRACTION ELEVATOR	HIGH SPEED 120~750 m/min	THYRISTOR-LEONARD CONTROL of D.C. MOTOR	INVERTER CONTROL of INDUCTION MOTOR
	LOW SPEED 30~105 m/min	PRIMARY VOLTAGE CONTROL of INDUCTION MOTOR	INVERTER CONTROL of INDUCTION MOTOR
HYDRAULIC ELEVATOR	30~60 m/min	FLOW CONTROL by VALVES with star-delta starting of INDUCTION MOTOR	INVERTER CONTROL of INDUCTION MOTOR for hydraulic pump

1980 1985 1990 1995

However, high-power and compact semiconductor modules were put to practical use in about 1980 and so called" power electronics" technology advanced rapidly with the progress of micro-processors. Using the above mentioned technology, we introduced inverter drive systems as driving control system to both high-speed elevators and low-speed elevators in the former half of 1980's. At present, the inverter drive system is adopted to the traction type elevators covering almost all speed and capacity ranges.

On the other hand, for hydraulic elevators, the conventional driving control method was to control the flow quantity of the oil which flows into or out of a hydraulic cylinder by valves. However, in 1990, we also introduced an inverter drive system for hydraulic elevators for the first time in the world. In this system, the oil flow is regulated by a variable speed pump which is driven by an induction motor controlled by an inverter.

3 TRACTION TYPE ELEVATOR

About 10 years ago, the first inverter control method was incorporated as a product into traction type elevators. In this space of time, many improvements have been made to this form of control, and the most up-to-date method will be described below.

3.1 Harmonic current reduction

Because an elevator is installed in a building, it is necessary to prevent the harmonic currents generated by the elevator from influencing other equipment in the building. At that time when we introduced inverter control system, the thyristor converter with the electric power regeneration function had been applied for high- speed elevators. But low-order harmonic currents are included in the converter input current in case of the thyristor converter. As a countermeasure, we recently applied the transistor converter which enable to remarkably reduce low-order harmonic currents by application of pulse-width modulation (PWM).

Fig. 1 shows the configuration of the drive control system using the transistor converter for high-speed elevators. Three phase AC power is converted into the DC voltage with the transistor converter once, then DC power is converted into the AC power of variable voltage variable frequency with the transistor inverter, and is supplied to the traction motor.

The converter, regulating the DC output voltage to a constant by a feedback loop control method, controls the input current to be in phase with the source voltage and maintain a power

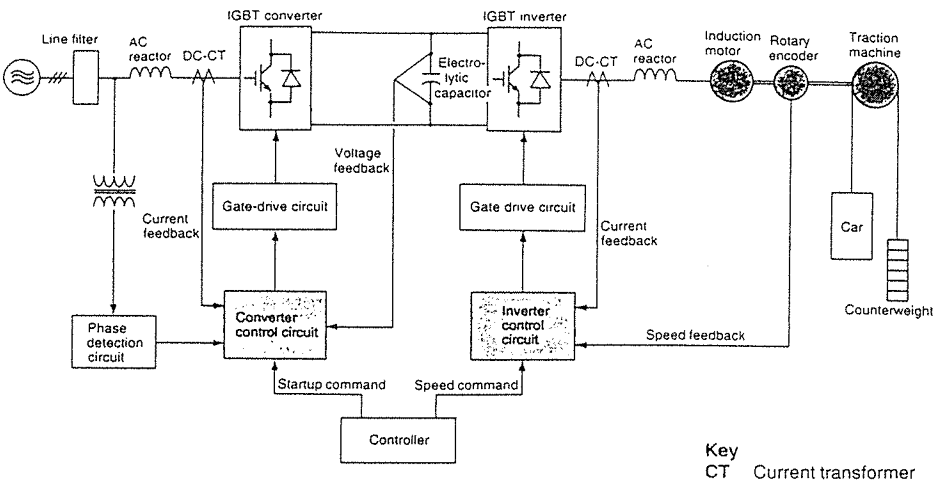


Fig. 1 Drive control system for high-speed elevators

factor of +l in the powering mode and -1 in the regenerative mode. Furthermore, the input current of the converter is pulse-width modulated and has a sinusoidal waveform similar to the output current of the inverter.

As a result, the power source capacity required for this system is 30% lower and the harmonic content contained in the power source current is reduced to 1/5 in comparison to the Thyristor-Leonard system.

The above control is processed by a digital signal processor (DSP), which functions as a converter controller and as an inverter controller including sinusoidal wave PWM control. As the controller is completely digital, a high level of accuracy and stability of control without drift can be realized.

Fig. 2 shows the waveforms of the input current and the source voltage. The harmonic current content is 5% or less.

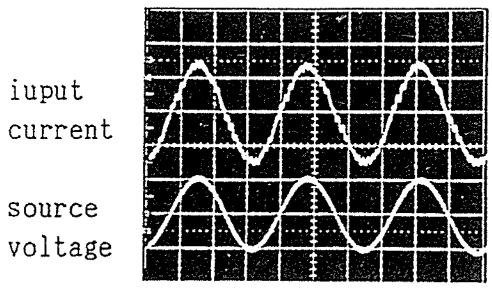


Fig. 2 Input current and source voltage

3.2 Acoustic Noise Reduction

When an electric motor is driven with an inverter, the PWM control method is generally adopted. In this case, the inverter causes audible motor noise due to the electromagnetic fields associated with power components at harmonics of the PWM carrier frequency. In reducing this noise, there is a method of making the carrier frequency greater than the audible frequency. However, previous power-switching elements used for elevator motors larger than several kilowatts have a maximum carrier frequency of 3kHz due to the limited switching speed, resulting in harmonics that create an unpleasant metallic sounding noise. This was reduced by inserting a reactor into the power circuit between the inverter and the motor to absorb high-frequency components. This measure is only partially effective, with the disadvantage that the reactor causes a voltage drop that lowers the inverter output.

We, at Mitsubishi Electric., have applied the insulated gate bipolar transistor(IGBT) to develop a high-frequency low audible noise PWM inverter.

Table 2 compares the characteristics of typical inverter switching elements. IGBTs are high-speed high-power devices capable of controlling power levels of several KVA to tens of KVA at high operating frequencies. They are also voltage-controlled devices, which means that they do not require the large transformers used in the drive-circuit power supply of current-drive devices.

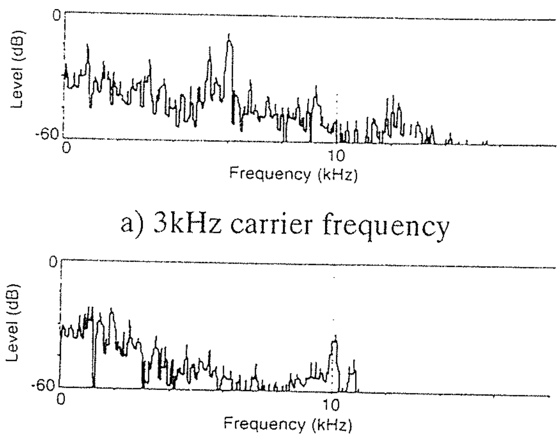
The switching speed of IGBTs are several times faster than previous bipolar transistors, allowing use of a carrier frequency of in excess of 20kHz. In practice, however, the maximum carrier frequency is limited by the switching losses which increase with carrier frequency. On the other hand, the motor acoustic noise will decrease with carrier frequency but almost saturate to that of motors driven at the commercial power supply if carrier frequency is over about 10kHz. So, a 10kHz carrier frequency is a good compromise.

Fig. 3 shows spectral analyses of the motor noise produced at 3 and 10kHz carrier frequencies without the reactor for noise reduction. Thanks to 10kHz carrier frequencies, the effects of the unwanted audio signals are greatly decreased.

This high-frequency PWM inverter with IGBTs is employed in high-speed and low-speed elevators. For high-speed elevators shown in Fig. 1, high-voltage high-collector current IGBT modules (1,200V/ 300A and 1,200V/ 600A) with a 10kHz carrier frequency is applied to both the inverter and converter. For low-speed elevators, wide ranges of IGBT modules (600V/100,150,200,300,400A,and 1,200V/ 300A) with the same carrier frequency are applied. And recently, the Intelligent Power Module(IPM) is taking the place of IGBT for low speed elevators. IPM is a new power module in which IGBT devices, IGBT driving circuits, and IGBT protection circuits are built in. IGBT protection circuits included are over-current, short-circuit, overheating and low voltage protection of control power supply.

Table 2 Comparison of Power Devices

Power device / Item	Bipolar transistor	MOSFET	IGBT
Drive method	Current	Voltage	Voltage
Carrier frequency	≤3kHz	≤60kHz	≤20kHz
Current capacity	Medium	Low	Medium
Breakdown voltage	Medium	Low	High
Short-circuit safety operation area	Good	Good	Poor
Saturation voltage	High	Low	Medium
Parallel connection	Facile	Facile	Facile



a) 3kHz carrier frequency

b) 10kHz carrier frequency

Fig. 3 Spectral analysis of motor noise

The IGBT or IPM inverter consequently have the following features.

(1) The noise of the motor was enabled to be reduced enough by the ripple of the motor current decreasing by making the carrier frequency high.

(2) Power consumption of the drive circuit was enabled to be decreased because IGBT or IPM is a voltage drive type, reliability improvement and the miniaturization of driving circuit were enabled to be achieved, especially, in IPM inverter, as driving circuit and protection circuit are built into the IPM.

3.3 Car vibration suppression

3.3.1 Reduction of Motor Torque Ripple

A motor driven by an inverter will generate a torque ripple easily by various factors. On the other hand, elevators require a comfortable ride. The elevator car is subject to vertical vibration that compromises riding comfort when the frequency of the torque ripple is equal to the natural frequency of the mechanical system. It is important to reduce the torque ripple of the motor as much as possible with the improvement of mechanical system for the vertical vibration suppression. Therefore, the torque ripple was reduced as follows.

(1) If the offset voltage of the DC current transformer which detects motor current exists, a motor generates the torque ripple of equal frequency with that of motor primary current. This offset voltage is automatically cancelled so that the motor current does not contain any DC component.

(2) Non-lapping time when no transistor elements in either of the arms of the bridge are activated, is designed in the PWM signal to prevent a short circuit between the upper and lower arms of the transistor bridge. This non-lapping time causes the distortion of the motor current and voltage, and the motor generates a torque ripple of the 6 times the frequency of motor fundamental primary current component. In high-speed elevators, to correct the above distortion, the inverter output voltage is fed back to a control device which will then compensate the PWM signals to eliminate such voltage disturbances. For low-speed elevators, the motor current is fed back to the motor current controller which has a high response feedback loop, then the current distortion is corrected.

3.3.2 High Performance Weighing Device for Low-Speed Elevators

For low-speed elevators, micro switches which operated by contraction of rubber vibration isolators mounted under the car had been commonly used as the weighing device or overload detecting device for the reason of low cost. This device, however, could not detect the load in the car continuously, thus riding comfort at start and landing was compromised. To eliminate the starting and landing shock, we have developed new type weighing device which detects the displacement of the shackle springs by the differential.transformer(s), resulting in detection of the load in the car continuously.

3.4 Large Capacity Inverter/Converter

To make the inverter/converter capacity large, switching devices are usually connected in parallel. However, each current of the switching devices will be unbalanced with the increase of switching devices. Therefore we have developed another method and applied it to the world's fastest passenger elevators travelling at speeds of 750m/min., which were delivered to the LANDMARK TOWER Bldg. in Yokohama. The configuration of drive system of this elevators is shown in Fig. 4.

Three 300A transistors are connected in parallel and this unit is linked to another three paralleled transistors unit through the reactor.

When inverters/converters are connected in parallel current will circulate between the inverters/converters. If excessive current circulates, the inverter/converter output will drop causing a reduction in the acceleration of the elevators. To avoid this, we have mounted the reactors on the output side of inverters and input side of converters. In addition, we control this circulating current to almost zero using digital signal processors, resulting in the circulating current staying within 5% of the rated current.

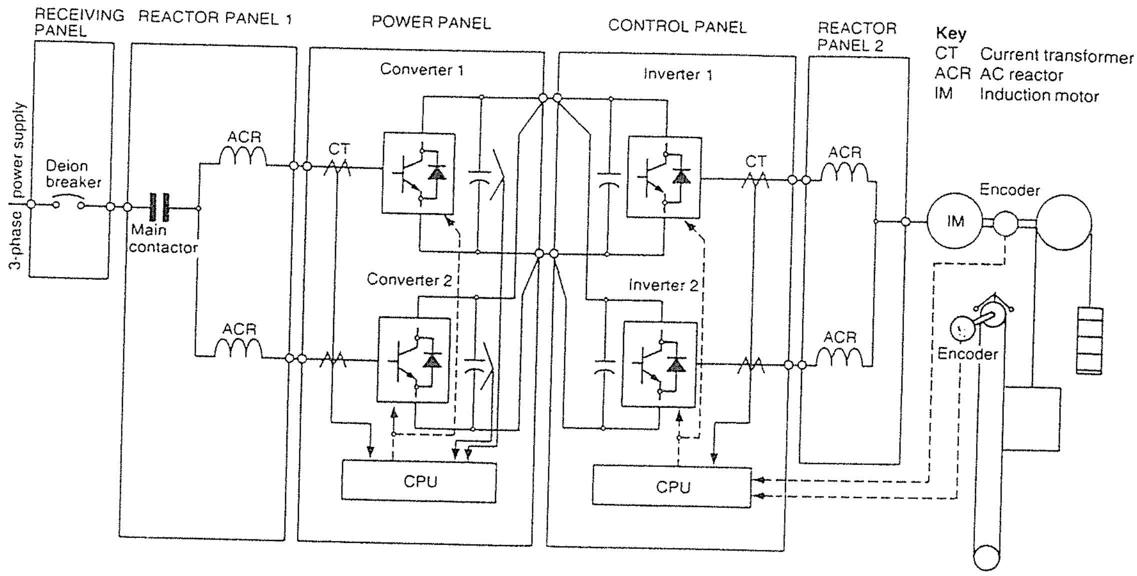


Fig. 4 Drive control system for 750m/min elevator

4 HYDRAULIC ELEVATOR

Fig. 5 shows the configuration of the driving control system of an inverter controlled hydraulic elevator. In this system, the motor driving circuit comprises a diode converter and a transistor inverter. The induction motor, of which the rotor shaft is directly combined with the hydraulic pump, is submerged in the oil reservoir along with the pump. The induction motor regulates the rotation number of the pump and directly controls bidirectional oil flows, i.e., from hydraulic pump toward cylinder during upward movement and from cylinder to hydraulic pump during downward movement, in response to the car speed command. This enables smooth control of the running speed at all stages and also elimination of the creeping speed zone before landings.

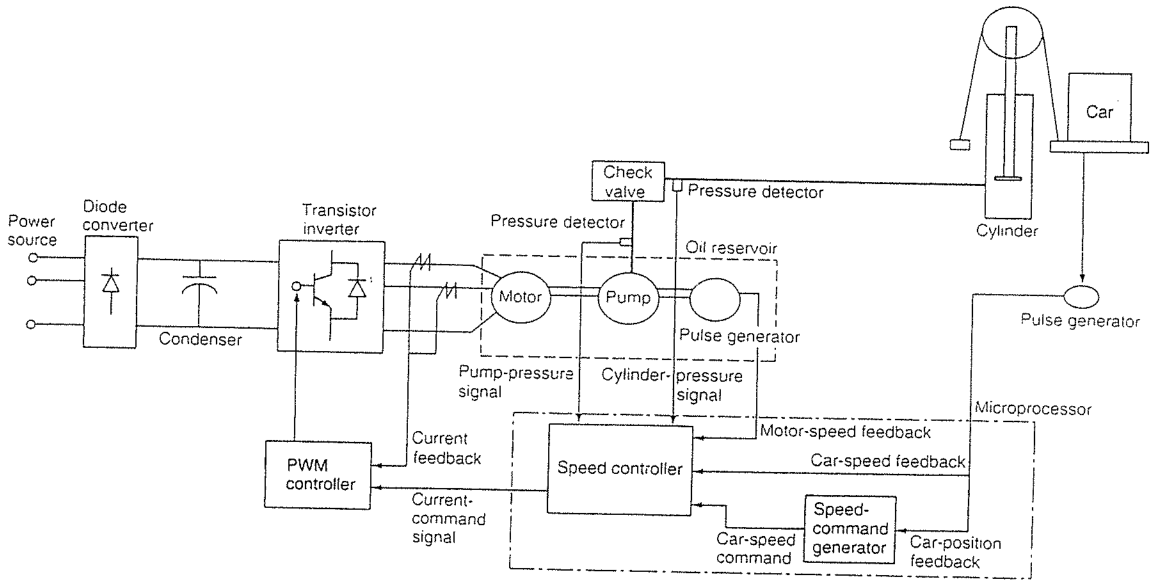


Fig. 5 Drive control system of an inverter controlled hydraulic elevator

In this system, the control feature is improved adding some control loops described as follows.

(1) Pressure balance control

To eliminate starting shock and ensure a comfortable ride, oil pressure on the cylinder side of the check valve and on the pump side of the check valve must be pre-balanced before the check valve is opened and the elevator car starts to move. In this system, the above mentioned pressure signals are sensed by two pressure detectors and sent to the speed controller, in which pre-balanced operation is carried out.

(2) Vibration Suppression control

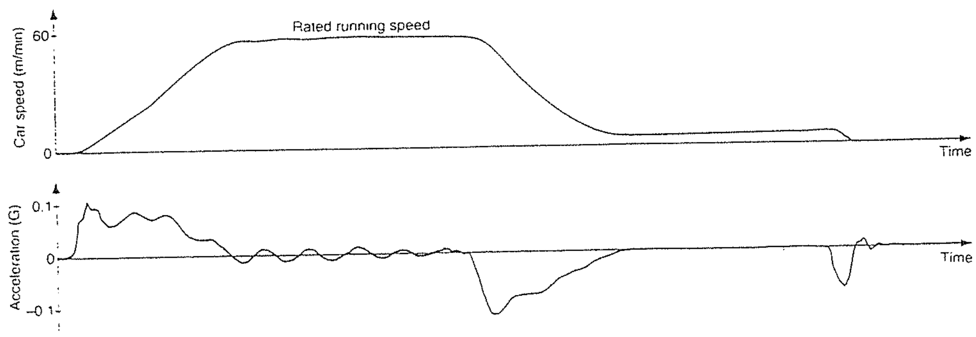
A hydraulic elevator system is a very low rigidity system. When any mechanical disturbance occurs at the jack cylinder by stick-slip between the hydraulic jack and rubber around the cylinder or at the guide rails and the car, it may cause a low frequency vibration on the car floor and compromise riding comfort.

In this system, vibration components contained in the oil pressure on the cylinder side of the check valve and in the car speed are extracted and fed back to controller, and the vibration is suppressed by the control loop.

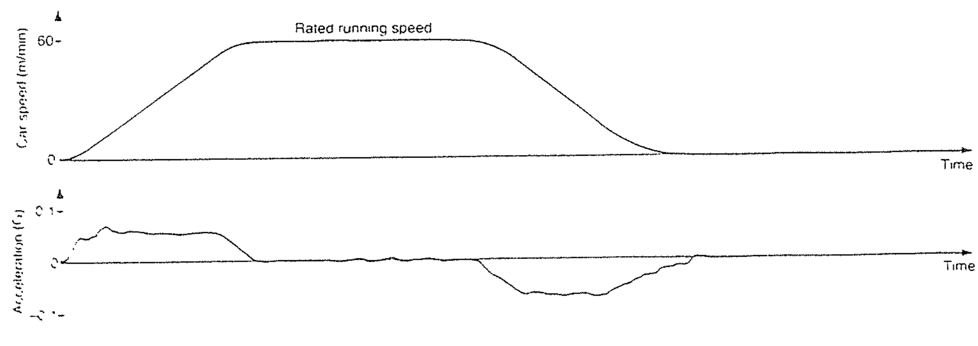
(3) Leakage compensation control

The hydraulic pump has a leakage flow and the speed of the car is not always proportional to the rotational speed of the pump, resulting in a speed fluctuation which can not be eliminated by only the motor rotational speed feed back loop. Therefore, to compensate this leakage flow, the car speed feedback loop is also applied. Due to this loop, favorable performances in car speed control and desired landing accuracy are realized.

Fig. 6 shows the characteristic operation curves of the inverter controlled hydraulic elevator as compared with conventional valve controlled hydraulic elevator. As can be seen



a) Conventional valve control



b) Inverter control

Fig. 6 Comparisons between conventional valve and inverter control from figure, it is obvious that inverter control gives smoother acceleration and deceleration characteristic, and no creeping is required when landing. These factors have enabled the elevator to achieve a more comfortable ride and higher operating efficiency, reducing floor-to-floor travel time by 20%. Power consumption has also been reduced by 15% as a result of the faster floor-to-floor travel time and the removal of the bypass flow for upward movement.

5 CONCLUSION

The latest drive technology which are applied both to traction elevators and hydraulic elevators were introduced here. The drive technology will develop with the advance of power devices, micro-processors and control theory, hereafter.

We, at Mitsubishi Electric, will continue our best efforts to develop newer elevators of higher performance and meet the requirements of our customers.

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