New Gear-less Traction Machine for High-Speed Elevators

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Abstract

Elevators require the miniaturization of the traction machine with less torque pulsation in order to ensure a smooth and quiet ride and to improve the layout of machine room. Mitsubishi has developed a new type of gear-less traction machine for high-speed and super high-speed elevators with the application of permanent magnet motor technology for which we researched for a long time. This is the first time to use permanent magnet motor for elevator.

The following is an outline of the main technical points.

(1) Torque pulsation reduction, miniaturization and high efficiency of permanent magnet motor.

(2) Detection of magnetic pole position and high accuracy in control of permanent magnet motor.

(3) Miniaturization of traction machine by using permanent magnet motor and double-disk brakes.

1. Introduction

In the history of traction machine with gear-less motor for high-speed elevators, the AC motor replaced the DC motor 10~15 years ago and since that time, the induction motor has been introduced.

The efficiency of rare earth permanent magnets is remarkably increased in the last 2 or 3 years, which resulted in increased production of magnets with high magnetic induction/high coercive force. This encourages the rare earth permanent magnet to be used in various applications.

Mitsubishi has developed a rare earth permanent magnet motor (hereafter referred to as the PM motor) with large capacity as an alternative to the conventional induction motor, which was previously used to drive the traction machines of high (more than 120m/min) and super-high (more than 300m/min) speed elevators.

This PM motor is superior to the conventional induction motor in the following points.

(1) High efficiency is obtained because an exciting current is not used.

(2) High frequency wave of magneto-motive force caused by motor slots and noise levels are low.

(3) Space for installation is reduced due to compact size.

This paper describes the development of the PM motor and its control method, in addition to the summary of the changes in gear-less traction machines and their technological progress, and the development of the disc brake to miniaturize traction machine.

2. Changes in the Mitsubishi Gear-less Traction Machine

We initiated the development for the gear-less traction machine for high-speed elevators in 1931 and installed the first produced elevators which were driven by the gear-less traction machine in 1936. DC motors have been used for more than 50 years since that time, and around 1985, they were replaced by traction machines using AC variable speed induction motors. At that time, a geared traction machine was used for high-speed elevators of 120m/min～240m/min and the gear-less traction machine was conventionally used only for super high-speed elevator of more than 300m/min.

The changes of the driving mechanism of high-speed and super high-speed elevators and its technological progress are shown in Table 1.

3. Specification of the traction machine

Table 2 shows the specifications of the newly developed gear-less traction machine for high-speed and super high-speed elevators. The disk brake was used for miniaturizing the traction machine. The shape of both the 25kw and 40kw motors and the brakes are the same.

4. Development of permanent magnet motor

In this chapter, we briefly describe the motor technology, taking a 40kw motor as an example.

4.1 Specifications of the motor

Rated output : 40 kW
Rated speed : 251 rpm
Insulation : Class F

4.2 Permanent magnet details

We used a rare earth magnet which has a high magnetic flux density and a large coercive force.

The three main materials used for permanent magnets are samarium(SmCo), neodymium(Nd) and praseodymium(Pr), all of which have the desired properties described above. For this project, we used an Nd magnet because as the maximum energy is increasing, it becomes more effective for miniaturization. In the Table 3, a comparison of each of the materials is shown.

4.3 Miniaturization method

The general method for miniaturizing a motor is to arrange Fig.1 multipole. This results in reducing core dimension and coil end length.

Power supply frequency is increased by a multipole arrangement, but the number of poles can be freely selected because of the recent advances in power electronics technology which has expanded the operating output frequency range of modern inverters, thus eliminating the frequency limitations in motor design. Since the block size of the magnetic material is limited for the PM motor, there is a limit to pole arc length to be covered by one magnet and the pole pitch lower limit value is also determined. Also, as the pole number increases, the number of components and the processing and manufacturing time are increased. Taking these points into account, the number of pole was selected.

The induction motor which has been conventionally used for the traction machine has some limitations for miniaturization because power factor and efficiency decreases when pole number increases. But, with the synchronous motor, high efficiency operation is obtained regardless of the number of poles, which allows the use of a multipole design and the miniaturization for the permanent magnet. Table 4 shows the comparison of induction motor and PM motor.

Table1. The changes of high speed and super high-speed elevators

TIME PERIOD	1930 1940 1950 1960 1970 1980 1990 2000
BUILDING OUTLINE	○START OF DEVELOPMENT FOR GEARLESS TRACTION MACHINE ○KYOTO MARUBUTU DEPARTMENT STORE (FIRST INSTALLATION) ◇GEARED TRACTION MACHINE WITH INDUCTION MOTOR ◇GEARLESS TRACTION MACHINE WITH INDUCTION MOTOR ◇TOKYO METROPOLITAN GOVERNMENT FIRST OFFICE ◇YOKOHAMA LANDMARK TOWER ◇T&C TOWER ◎GEARLESS TRACTION MACHINE ○SHINZYIKU SUMITOMO ○SUN SHINE 60 ◎JINMAO
DRIVE CONTROL SYSTEM	○WARD-LEONARD CONTROL OF D.C. MOTOR ○THYRISTOR-LEONARD CONTROL OF D.C. MOTOR ◇VVVF CONTROL OF INDUCTION MOTOR ◎VVVF CONTROL OF P.M MOTOR

Table.2 Specifications of traction machine

Rated speed	120～240m/min	300～540m/min
Maximum Capacity	1600kg	4000kg
Motor	25kw…120,150m/min 40kw…180～240m/min	Max.210kw
Brake	Disk brake type 2Coils 2Plungers	Disk brake type hydraulic release

Table 3. Comparison of rare-earth magnets

	SmCo	Nd	Pr
Max.B-H product	○	◎	○
Thermal property	◎	◎	△

◎ : superior ○ : good △ : inferior

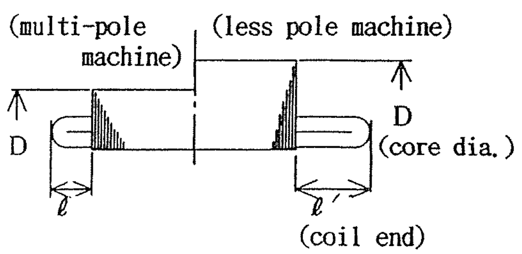

Fig.1 Effect of number of poles

Table 4. Comparison of induction motor and PM motor

	Induction motor	PM motor
Power factor	63%	94%
Efficiency	90%	92%
Volume	100%(Base)	65%

4.4 Rotor structure and protection

Although the strength and processability of the rare earth magnet has been greatly improved, it is generally difficult to make holes in the magnet itself. For this, we fixed the magnet with non-magnetic spacer. Because of the limitation in the block size, the several magnets are arranged to the axis direction for one pole. The magnet is structurally made so that it will not be directly affected by factors such as external atmosphere (chemical gas, moisture etc.,) and dust collection.

4.5 Endurance against demagnetization

The magnetic property is classified into the reversible and irreversible range depending on the scale of the external magnetic field (Fig.2). This property is easily influenced by magnet temperature, so the higher the temperature becomes, the narrower the reversible range becomes. Therefore, we kept the temperature as low as possible and took the reactance of the motor into consideration so that the opposing magnetic field caused by armature current would not exceed the reversible range and magnet demagnetizing would not occur. Also, in the short-circuit testing for models we confirmed that the demagnetizing did not occur. Fig.3 shows the analysis of the opposing magnet field Hd working on each part of magnet subject to short-circuit current I.

4.6 Countermeasure for torque pulsation

If the induced voltage in the motor has a harmonic component, high harmonic current flows as a result of the difference between the induced voltage and the sinewave voltage of power source, which causes torque pulsation. Since the traction machine for elevator requires less pulsation and smooth torque generation, we arranged the armature in 1 slot skew and selected the fractional slot design with an adequate winding constant in order to improve the wave form. As a result, the much improved wave form of Fig.4 was obtained.

5. Permanent magnet motor control

Fig.5 shows the drive control system for a high-speed elevator using the permanent magnet motor.

The inverter allows the permanent magnet motor to provide accurate speed and torque by feedback control which controls speed as a return signal, and by a minor current loop which controls output current and pole position as a return signal. This ensures a comfortable ride for elevators.

Compared with the induction motor, the control of the permanent magnet motor is simple, so that the loss time can be reduced in the starting of motor and the good motor efficiency can be obtained due to exciting current becoming unnecessary.

The converter controls the output DC voltage to hold the constant value by feedback control, which uses output voltage as a feedback signal, and by current minor loop, which uses input current as a feedback signal, and the power factor of input current to make 1 in power and -1 in regeneration by detecting the phase of supply power voltage. Here at we adopted IGBT modules with high breakdown voltage and high current capacity (rated voltage 1200V, rated current 300A or 600A) for main circuit element of converter and inverter, setting carrier frequency to 10KHz. As a result, this reduced relative magnetic noise generated by motor and ensured quiet running for elevator.

Regarding the application of permanent magnet motor, we describe the characteristics of the newly adopted drive control system.

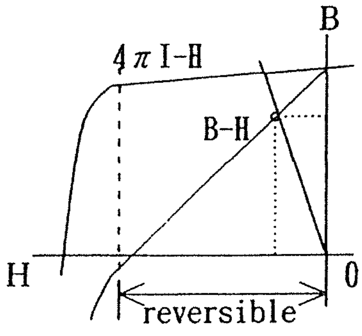

Fig.2 Magnet reversible range

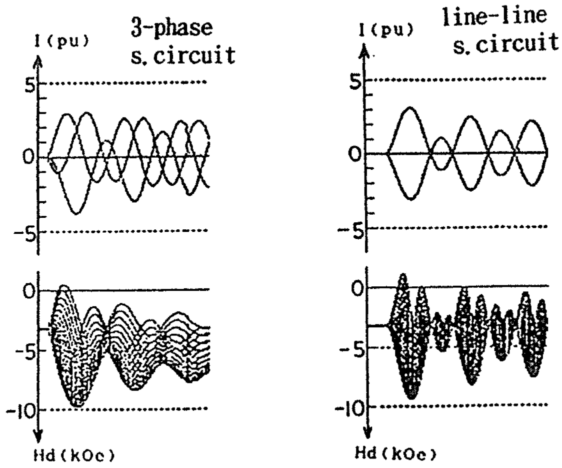

Fig.3 Analysis of short-circuit field

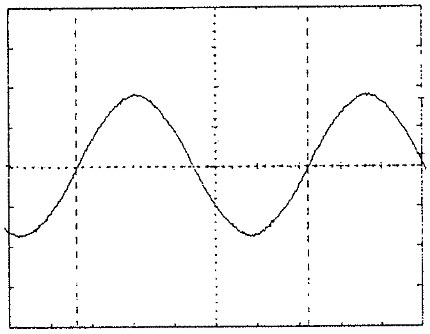

Fig.4 Waveform of induced emf

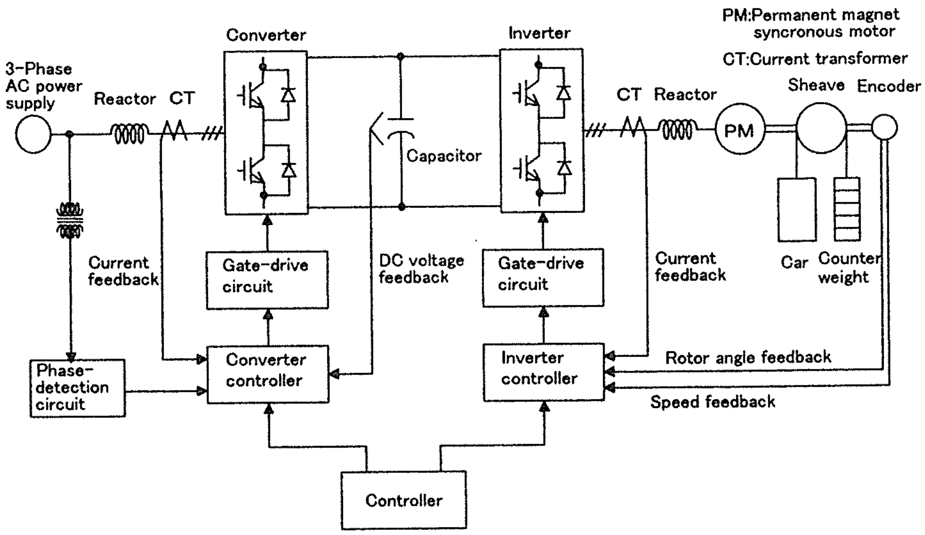

Fig.5 Drive-control system

5.1 Control circuit

A permanent magnet motor generates the field magnetic flux by revolving the permanent magnet and allowing the armature current to flow, the vector product of which generates torque.

The torque of permanent magnet motor is given by the following formula.

$$T_e = p\, \Phi_{fa}\, i_{qa}$$

T_e : motor torque

p : pole pair numbers

Φ_{fa} : coil interlinkage magnetic flux

i_{qa} : armature current directly crossing to Φ_{fa}

Therefore, depending on the magnetic pole position which is detected by the magnet pole position detector(described below), the motor controls the armature current so that the field flux and the armature current vector may cross, allowing the high accuracy control for motor torque. In this control, a digital signal processor was used and a high-speed response was also achieved.

5.2 Magnet pole position detector

To control permanent magnet motor, the magnet pole position should be detected. Therefore, in detecting magnet pole position, we used a highly cost-effective encoder having two functions :

1. An absolute encoder which detects the absolute position at an electrical angle of every 45 degrees.
2. An incremental encoder which continuously outputs two phase signals and a zero signal giving one pulse in one rotation.

5.3 Magnet pole position correction

When assembling the encoder in the traction machine, the error is always caused at the absolute position of the magnet pole. But, even if this value is a very small mechanical angle error, it may result in several times error for the electric angle, resulting in a severe detection error. The detection error of magnet pole position deteriorates control performance of torque, which may even affect the ride performance of the elevator. Therefore, a magnet pole position correction circuit, which estimates the detection error of the magnet pole from the state data in car was adopted.

5.4 Running wave form

Fig.6 shows car running wave form.

6. Brake

6.1 Brake system

This traction machine uses a double brake system with two disk brakes as an alternative to the drum brake. In this chapter, we compare the drum brake used for gear-less traction machine and double brake in the respects of layout, maintenance and efficiency. Table 5 shows the characteristics respectively.

6.2 Coil structure

The external dimensions of the brake are determined by coil size. For this brake, a clapper type coil with a small external size was adopted.

Fig.7 shows a lever brake using a clapper type coil. Since the external shape of the coil is determined by the coil stroke and absorptivity, it is required to use a coil with external shape as small as possible taking layout and maintenance into consideration. Through the adoption of clapper type coil, the coil stroke has been drastically reduced compared with the conventional solenoid coil.

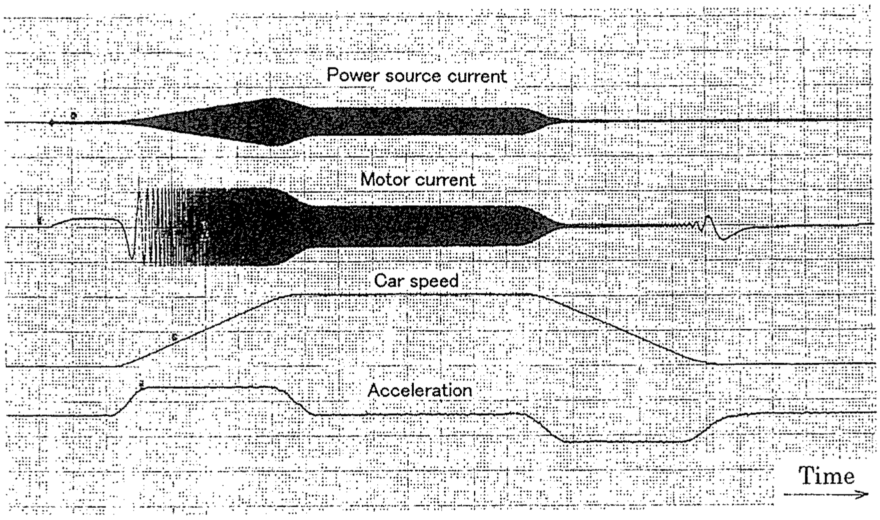

Fig.6 Drive performance under full load

Table5. Comparison of brake system

	Drum Brake	Disk Brake
Layout	○	◎
Maintenance	○	○
Efficiency	○	◎

◎ : superior ○ : good

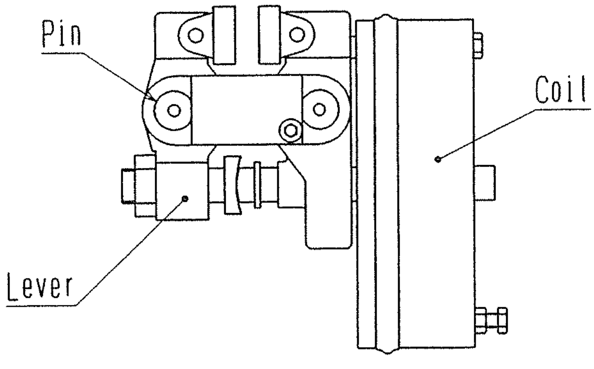

Fig.7 Disk brake(lever type)

6.3 Coil stroke reduction

The floating type was adopted as an alternative to the lever type to further miniaturize coil stroke. Fig.8 shows the external drawing of floating type disk brake. With this arrangement, the stroke was further reduced to 40% compared with the lever type because backlash and loss around the lever supporting pin and the lever deflection were negligible.

6.4 Hydraulic brake system

As a brake for the traction machines of elevators with speeds over 300m/min, we have newly developed a hydraulic release disc brake in response to the need for increased braking torque. Double brake systems equipped with two brakes have been adopted. Through this hydraulic release type disc brake, the miniaturization of the brake assembly has been achieved and a flexible arrangement is offered.

7. Miniaturization of traction machine

7.1 Projected area of traction machine

The external drawing of the traction machine is shown in Fig.9 and the comparison drawing of project area between geared and gear-less traction machines in Fig.10. The solid line area is a conventional geared traction machine and the slanting line area is a gear-less traction machine. The projected area of machine room occupancy is mostly determined by reduction of the gears and the motor. In order to make use of the limited space, the combination of the geared reduction machine plus the induction motor has been conventionally applied for this area. We have adopted a gear-less traction machine using a PM motor as an alternative to geared reduction machine and reduced the projected area to some 80 %. Also, as a result of using a PM motor which is shorter than induction motor in the axis direction, the layout of machine room has further improved.

8. Conclusion

Mitsubishi is the first manufacturer to develop this new gear-less traction machine for high-speed and super high-speed elevators using a permanent magnet motor. The following results have been proved by using this traction machine.

(1) Permanent magnet motor does not need exciting current. This has resulted in an improvement in the control performance and in the running performance.

(2) The undesirable generation of a high frequency sound wave has been decreased by the permanent magnet motor. This ensured even lower noise and lower vibration, resulting in an improved ride, compared with the conventional inductor motor.

(3) Through the use of the miniaturized motor and double disk brake, the traction machine has been miniaturized, enabling the layout of machine to improve.

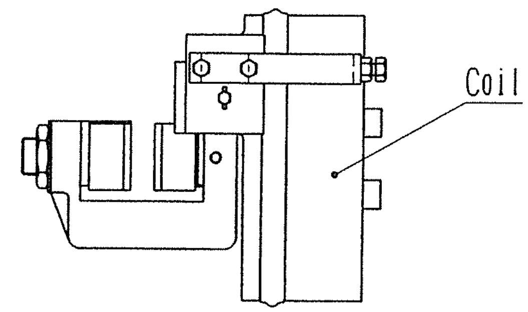

Fig.8 Disk brake(floating type)

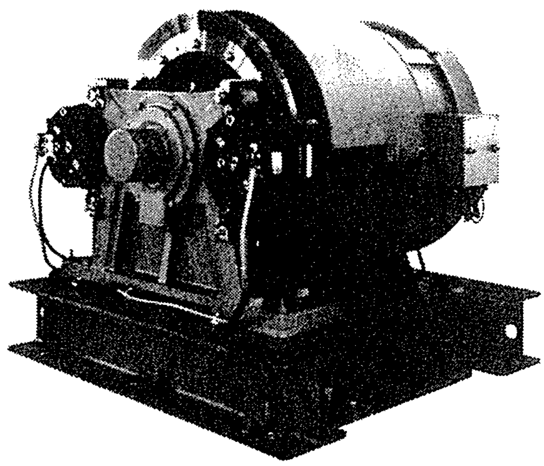

Fig.9 Gear-less traction machine

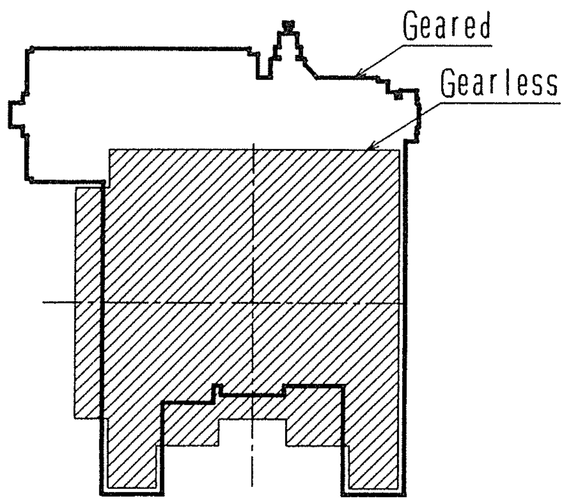

Fig.10 Comparison of traction machine

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