A New Door Driving System
Realizing Quick and Silent Motion

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ABSTRACT

We have developed a new door driving system which opens and closes elevator doors smoothly and silently. For a smooth door motion we developed a new gripping link mechanism which is catch the floor doors with a minimum of motion. To design this link mechanism we used a static analysis method.

For a silent door motion, we developed a new AC-motor controller which reduces the electric current distortion and the torque ripple of the AC-motor to make it work more quietly.

1. INTRODUCTION

In recent years more multi-story buildings are being built. Many of these buildings are utilized for special purposes such as offices or high-class hotels. Elevators in such buildings are required to work smoothly and silently. In particular for daily users, elevator door systems receive much notice. Two major problems, however, spoil smooth and silent motion of elevator door systems. One problem is that an elevator door system is composed of two parts, the car door and the floor door. Since the door driving machine is connected only to the car door, the car door has to open earlier than the floor door in an opening motion. On the other hand, in a closing motion, the floor door has to close before the car door does. So the car door slows down earlier to allow the floor door to close silently. This makes the door movement less smooth. The second problem is the noise of the moving doors. In many office buildings the level of background noise is very low, so silent movement is required. The suppression of door noises, however, is very difficult, because these noises have many sources.

In order to realize a smooth and silent elevator door driving system, first, we developed a new gripping link mechanism, which is catch the floor doors with a minimum of motion. This reduces the distance between the car door and the floor door and the time it takes for the doors to slow down in order to close silently (half the distance compared to the current gripping system).

Second, we developed a new high performance driving controller for elevator doors, based on our analysis of noises and vibrations of the door system. According to our frequency analysis, the dominant noise source is distortion of the AC-current wave of the driving motor. To lower the distortion, our driving controller uses a new microprocessor. This reduces the electric current distortion to 8dB and makes the elevator doors work more quietly.

2. QUICK GRIPPING SYSTEM

2.1 Configuration of the new gripping system

Figure 1 shows the door link system. The doors hang on a rail from a hanger by rollers and are guided by a sill under the door. The link mechanism connected to pulley 2, which is rotated by the AC-motor, moves the car doors horizontally. The gripping

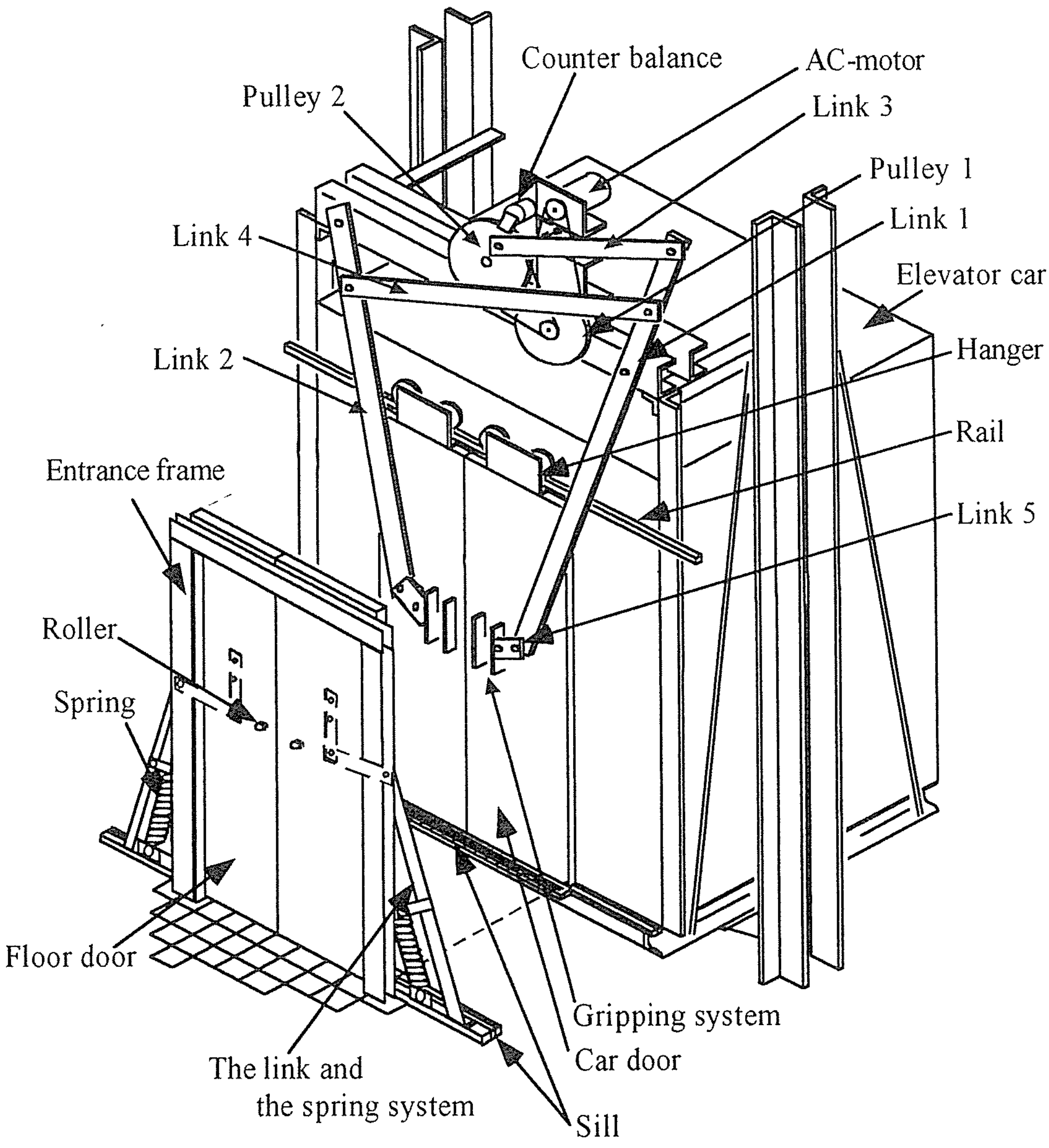


Fig.1 Configuration of the door link system

system on the car door catches the rollers on the floor door and each door moves simultaneously. The floor door is forced to close by the link and spring system.

Figure 2 compares our new gripping system to the current one. The movement of the gripping system is as follows.

(1) The car door starts to move.

(2) The bracket on the left side touches the roller and the floor door starts to move.

(3) The gripping system holds the roller firmly.

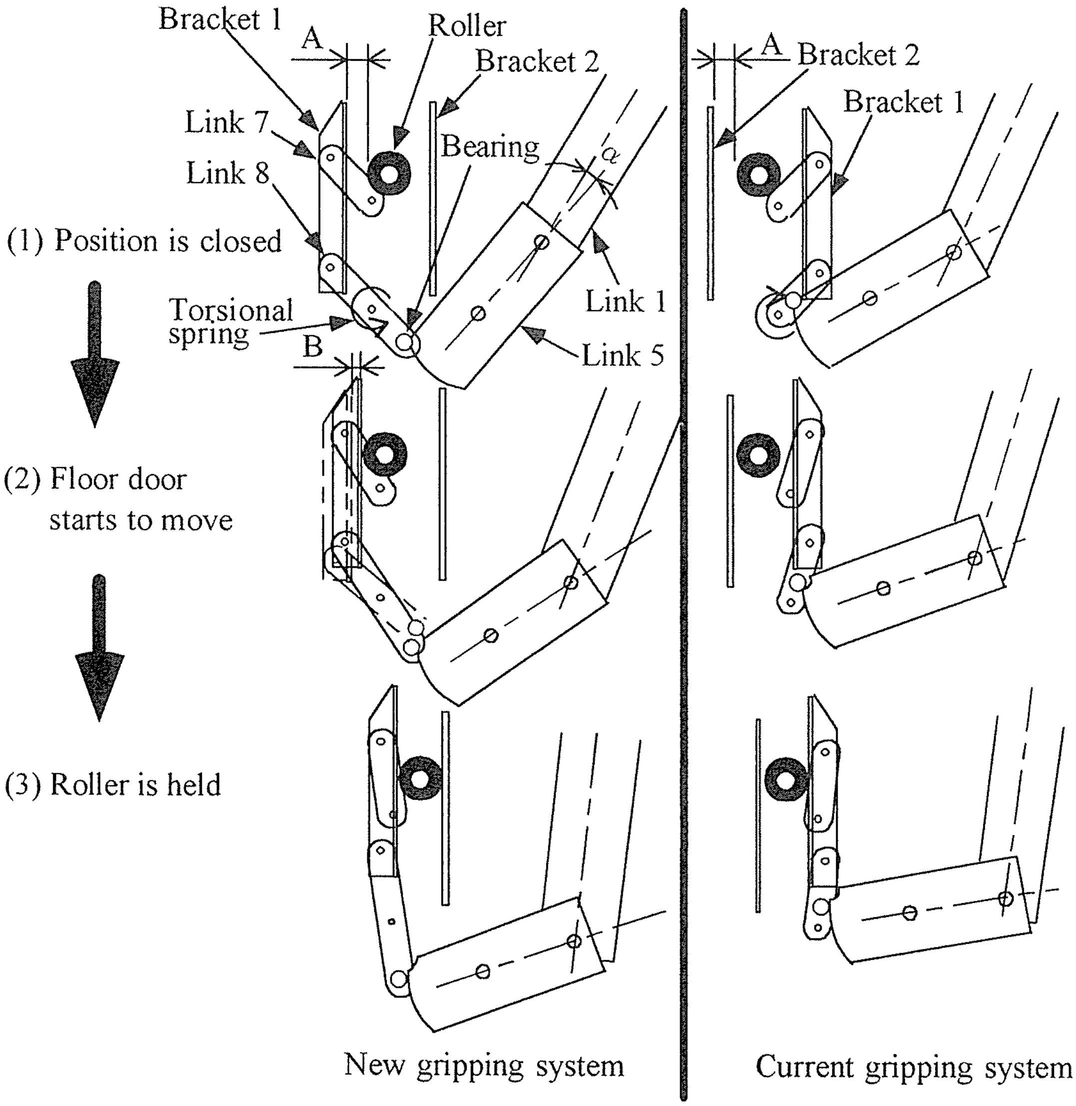


Fig.2 Comparison of gripping systems

Link 5 has a curved end on which the bearing can move. Links 7 and 8 are connected to Bracket 1 which changes position if the bearing is moving. Link 8 is connected to a torsional spring so it pushes the bearing against Link 5.

Bracket 2 of the current gripping system is fixed on the car door, and it touches the roller on the floor door. The floor door starts to open when the car door moves distance A. On the other hand, with our new gripping system, Bracket 1 moves distance B towards the roller. So the distance is reduced to A-B. In order to enhance the effect of the shortened distance, Bracket 1 must move quickly and Link 5 has to rotate fast, too. Thus, we designed the angle α as nearly 0 degrees, and set the joint between Links 1 and 5 as a singular point. This arrangement makes Link 5 move quickly in a short period at the beginning of the opening motion. These two features, the moving bracket to catch the roller quickly and the singular point arrangement between Links 1 and 5, realize a quicker and smoother door movement .

2.2 Analysis of the static force

In order to realize a new gripping link system, we applied a highly precise kinematic balance analysis. In an emergency, for example an electric power failure, it must be possible to open the elevator doors to enable passengers to rescue. Therefore, the static force needed to open the doors must be of a certain value.

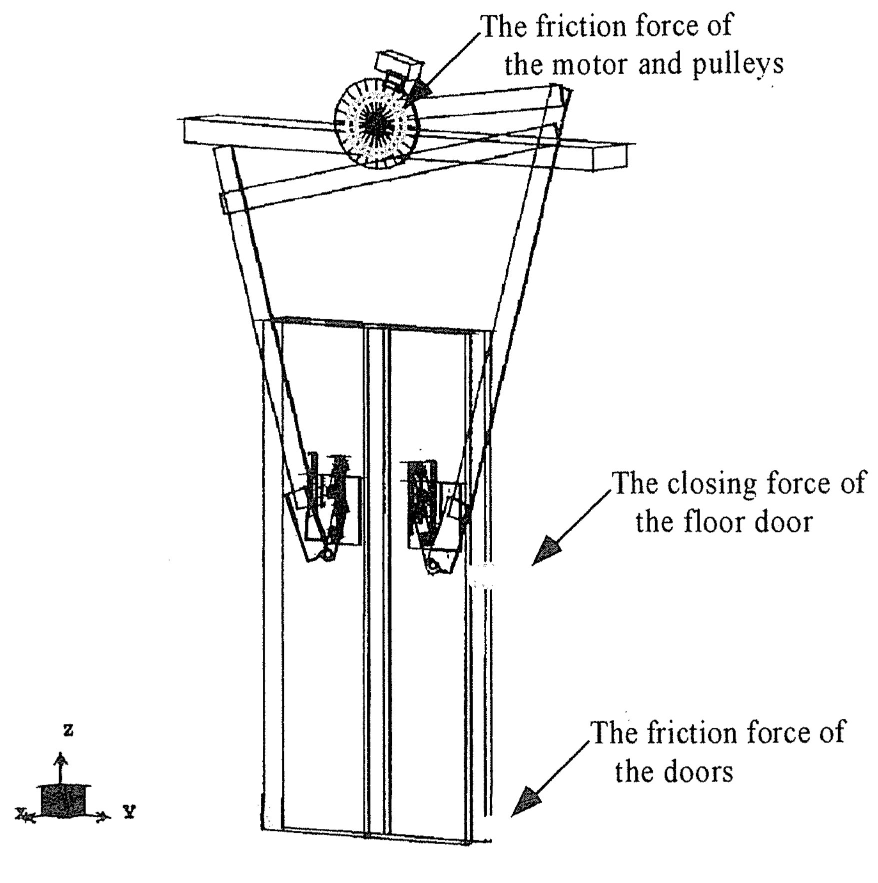


Fig.3 The model of the door driving system in DADS

It is difficult, however, to calculate the force needed to open the doors because part of the link relation is singular when the doors are closed, and also, the number of components of the link mechanism is twice that of the ordinary one. Thus, extremely precise analysis is required to compensate for the mechanical balance. To realize this kinematic analysis, we used the mechanical analysis software, DADS (Dynamics Analysis and Design System) of CADSI, for these calculations. Fig. 3 shows a 3-D model of the door driving system in the GUI modeller of DADS.

The elements of the force affecting the kinematics balance of the door system are as follows.

(1) The gravity force of the mass of the links and the counter balance.

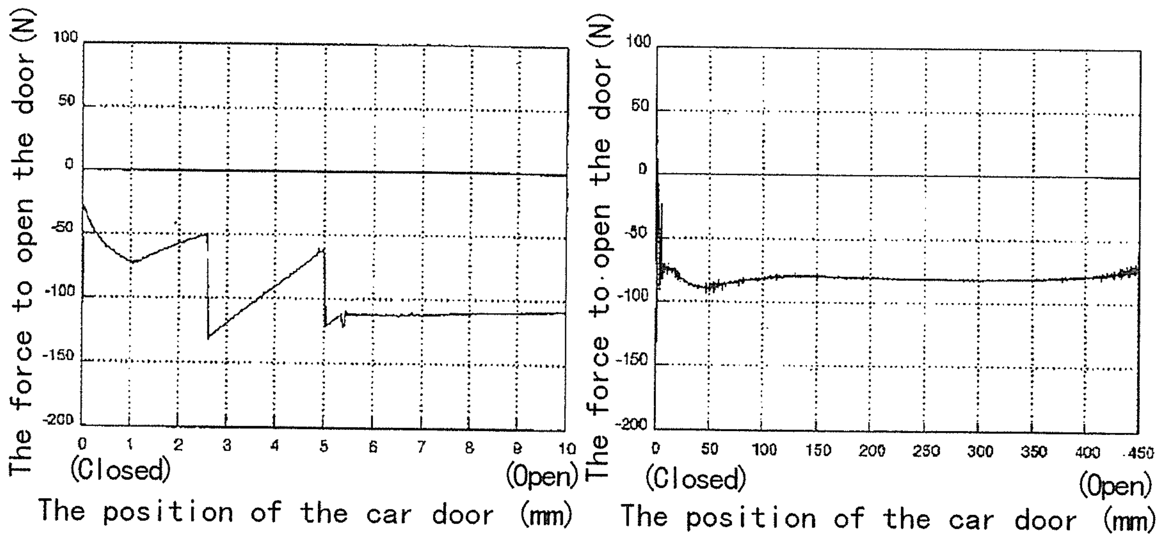
(2) The gravity force of the mass of the gripping links and the bracket, and the reaction force of the torsional spring.

(3) The friction force of the motor and the pulleys.

(4) The friction force of the doors.

(5) The closing force of the link and the spring system on the floor door.

Figures 4 (a), (b) show results of the DADS calculation. We examined the accuracy of the analytical results and confirmed that the error of this analysis is within ± 10N.



(a) Near the closed position of the car door (b) All positions of the car door

Fig.4 Results of the DADS calculation

3. REDUCTION OF NOISES

3.1 Analysis of noises

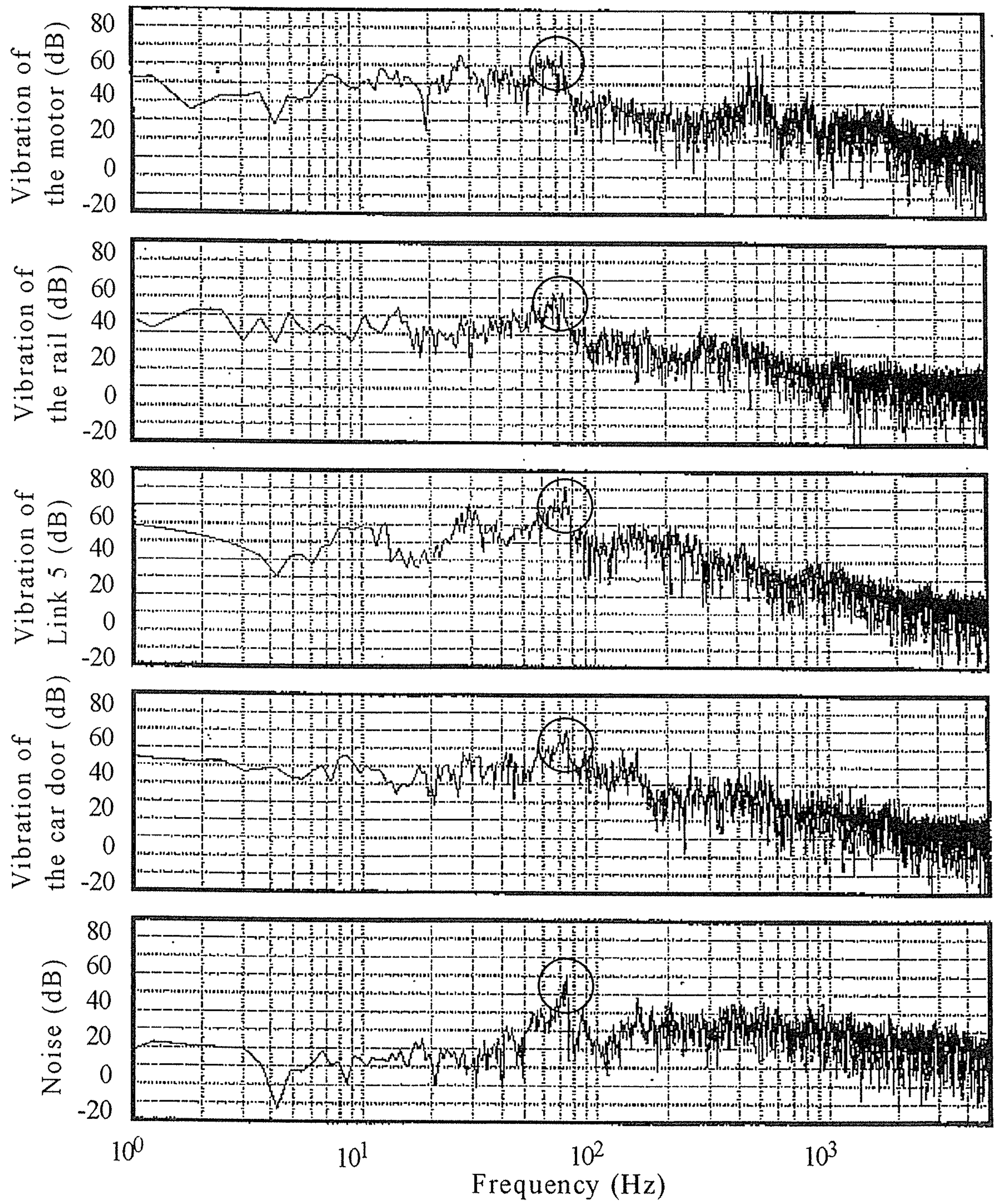
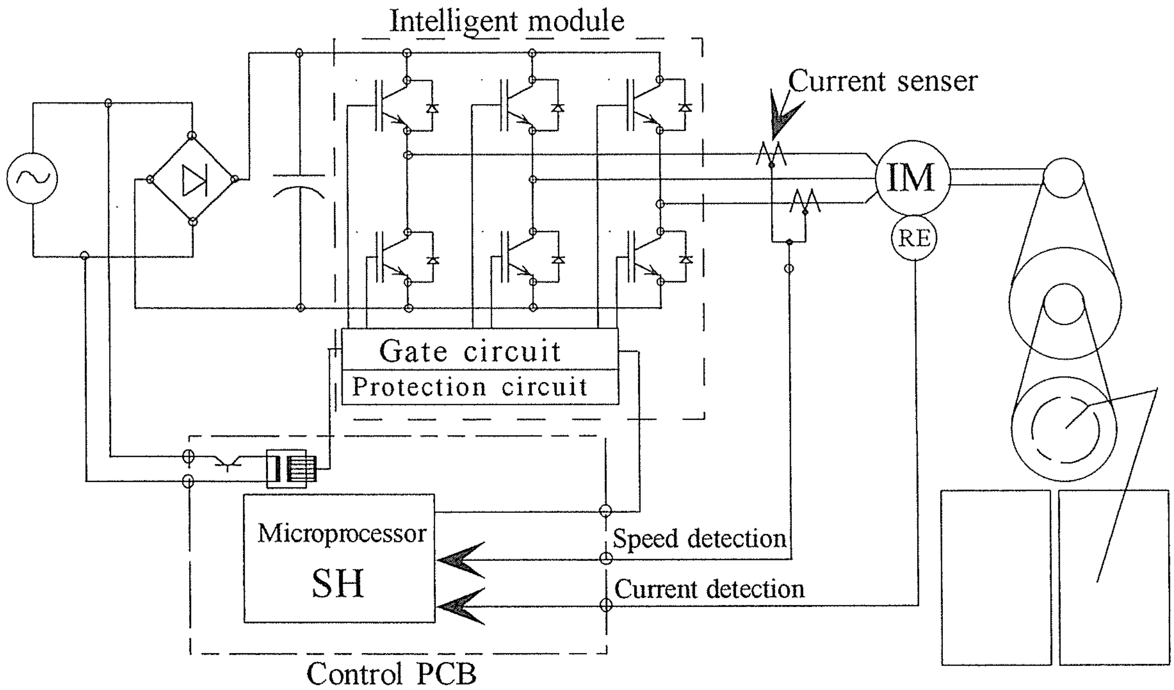


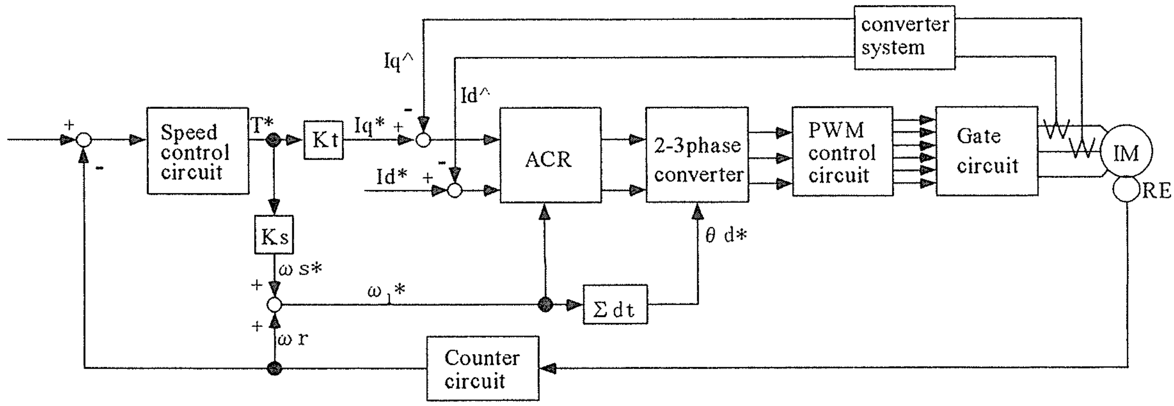
Fig.5 The analysis of noises and vibrations

Noises of door movement have many sources. In order to investigate what is the major source, we measured and analyzed vibrations and sounds of several parts of the door driving system. Figure 7 shows results from the vibrations and the sounds. These results show that the peaks are always located near 75Hz, which is close to a frequency six times that of the AC- current wave of the driving motor. The distortion at this frequency is known to be due to an error in high speed switching of an IPM (Intelligent Power Module). Thus, the results of Fig.7 indicate that the main source of the noises is the switching error of the IPM.

3.2 The new door control system



(a) Configuration of the door control system



(b) Block diagram of the door control system

Fig.6 The new door control system

To reduce the distortion of current, we developed a new door control system. This control system uses a new microprocessor the SH processor, and it works with RISC architecture. The controller can execute a control process quickly and also compensate for the switching error of the IPM[1]. Figure 6 illustrates the configuration and the control block diagram of the new door control system.

The new door control system is composed of the following subsystems.

(1) Speed control system.

The speed control circuit is based on an ordinary PI (Proportional-Integral) control law. In addition, since the door driving system is composed of a non-linear link mechanism, the control law is arranged to compensate for the non-linear effect by the gain scheduling method.

(2) Current control system.

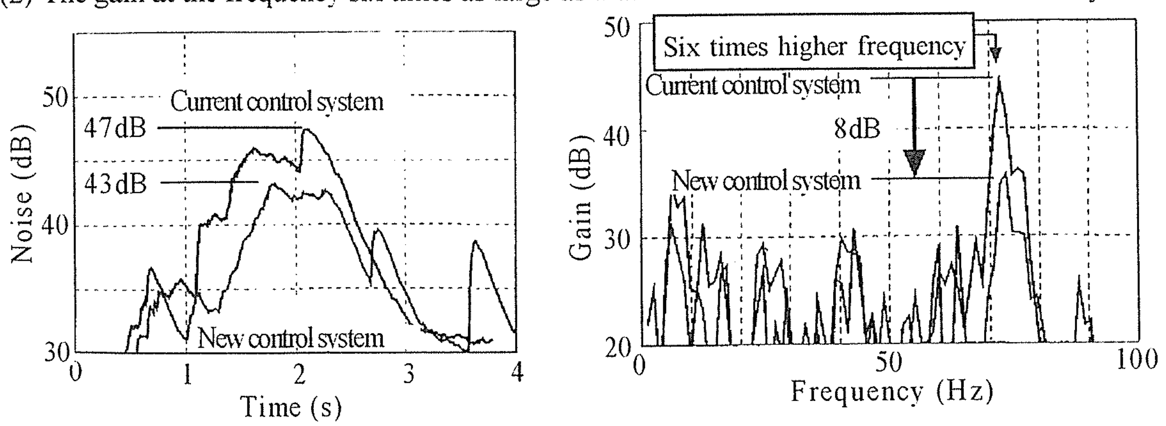
The current control system is divided into two parts. One part is the vector control system, which determines the current reference signal from the torque reference based on the vector control law. The second part is the current following system, which is an ACR (Auto Current Regulator). The output from the ACR is sent to the PWM (Pulse Width Modulation) switching circuit. The new SH microprocessor realizes a high sampling speed ACR and also a small error switching.

3.3 Experimental results

We carried out experiments with actual size equipment in order to verify the effectiveness of the new control system. Figure 7 shows the overall level of noises and the results of the frequency analysis. Figure 7(a) compares the noise of the new control system to the current one. Figure 7(b) compares both regarding the gain level of noises. These results shows the effectiveness of the new control system.

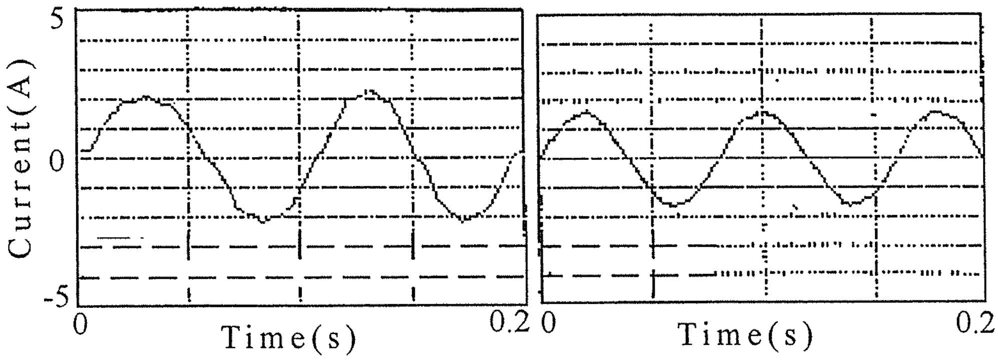
(1) The overall value of noises is reduced by 4dB

(2) The gain at the frequency six times as large as that of the AC-motor current is reduced by 8dB.



(a) Overall level of noises **(b) Gain level of noises**

Fig.7 Results of noise measurements



(a) The current door control system (b) The new door control system

Fig.8 Comparison of the current curve

Figure 8 compares the current curve. It is clear that the distortion of the new door control system is considerably reduced.

4. CONCLUSION

The new door driving system with a quick gripping system and a new control system has been developed. This driving system realizes an extremely smooth and silent elevator door system.

(1) With the quick gripping system the low speed motion period of the car door near the closed door position was reduced to a half. This made the door movement smoother.

(2) It was confirmed that the analysis of the static force of the link system was sufficiently accurate.

(3) The noise of the door with the new door control system was reduced by 4dB.

REFERENCE

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