The design of permanent magnet variable-frequency door-motor with one-driver dual control

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Abstract. Aiming at the scarcity for matched high-end door-motor to domestic high-velocity elevator market, with the research on domestic and overseas elevator door-motor control technology and permanent magnet synchronization technology, a high-end door-motor system that matched with high-velocity elevator and even ultra-high-velocity elevator has been put forward. It introduced in detail about the door-motor control hardware design that used digital chips and intelligent power module as its main circuit, how to realize the door-motor operation curve with SVPWM (Space Vector Pulse Width Modulation), the orientation angle learning method of permanent magnet synchronization motor, how to work in parallel for dual-motor and how to switch the single motor as well as the overall mechanical design scheme. The actual door-motor operation curve has been surveyed through experiment and the operation curve has been analyzed. The research results indicate that the door-motor system can suffice the design requirements input and the design scheme is reasonable and reliable, which will not only significantly shorten the opening and closing time compared to the ordinary door-motor and distinctly improve the service efficiency of high-velocity elevator, but also make the operation curve of the door-motor more graceful, quieter, more stable and safer.

1. Introduction
People normally refer the elevator with maximum operation velocity higher than 2.5m/s as high-velocity elevator, and for the one with maximum operation velocity higher than 6.0m/s, they call it as ultra-high-velocity elevator. The new maximum operation velocity of elevator will be set every few years. Right now, the fastest elevator in China is Hitachi that installed at CTF finance center in Guangzhou, its maximum velocity is 21m/s [1]. People are paying more attention on the faster operation velocity of elevator, however, they pay less attention on the operation velocity of opening and closing system that has more frequent movement and more contact with people inside the elevator, which lead to the imperfection of opening and closing system applied to domestic high-velocity elevator. The requirements of the door system applied to high-velocity elevator: suitable for civil engineering of high-rise buildings, resistant to wind pressure while in high-velocity operation, short opening and closing time, high efficiency, low noise and more reinforced door panel. The ordinary door system installed on high-velocity elevator will bring impact on its performance and safety. In light of the scarcity of such products in domestic market right now, it is significant to research and develop a high-end door system.
that has excellent performance and reliability and with graceful operation curve which is applied to high-velocity elevator, in addition to that, the market potential is tremendous [2].

Currently, the dominated door-motor adopts variable-frequency and variable-voltage technology. The door-motor control variable-frequency devices on the market almost fully realize the digital control [3]. The adoption of digital signal processing enables the fast operation and high-accuracy control as well as an excellent current waveform, which will significantly shorten the scanning time. Digital control is the core technology for static variable-frequency devices as well as the developing trend in future [4].

Opening and closing time is a crucial indicator for door-motor, the shorter the opening and closing time, the shorter the staying time at each level for elevator, as a result, the higher the running efficiency [5].

2. Door-motor theoretical operation curve and signals

According to ideal operation velocity curve of elevator and combining the operation curve of variable-frequency door-motor, the door-motor theoretical opening and closing curve has been worked out by synthesizing various factors under the premise of sufficing fast velocity, stability and comfort ability. As shown in figure 1.

![Door-motor theoretical opening curve and signals](image)

**Figure 1.** Door-motor theoretical opening curve and signals

- Vertical axis refers to the operation velocity of door-motor, horizontal axis refers to the moving distance of door-motor
- Point O: The limit point for the door closed in place, there is no velocity for the point, only a stalling torque to maintain the closing status.
- OA: The acceleration zone for opening, an arc has been adopted in the acceleration process to reduce impact.
- AB: The constant velocity zone for opening, in this zone, the motor is running at the set maximum velocity.
- BC: The deceleration zone of opening, a decelerated arc has been adopted for transition, which enables smooth deceleration process of door-motor.
Point C: The limit point for the door open in place, there is no velocity for the point, only a stalling torque to maintain the opening status.

The signals for opening and closing are the one that sent to door-motor control from system. The arrival signal of opening and arrival signal of closing are the feedback for door-motor controller to system, black refers that the signal is continuous and valid.

The door-motor theoretical closing curve is similar with the opening curve, so, we will not bore you with more details here.

The curve has high running efficiency. Each velocity abrupt zone adopts rounded corner as transition, the curve is smoother, which will minimize the mechanical impact of motor acceleration and deceleration on the whole elevator door-motor system and significantly lower down the noise in running process.

The door-motor theoretical opening and closing curve is the core of the whole door-motor design. The final design result test is also based on the theory that the opening and closing curve can be realized within the designed time.

3. The design of permanent magnet variable-frequency door-motor controller with one-driver dual control

The door-motor controller is the brain of the whole door-motor. The receiving of input instruction, running status feedback, processing the encoder position signal, analyzing door-motor operation curve, controlling the motor output and the interaction of manipulator interface are all completed through door-motor controller. Therefore, the successful design of door-motor controller is the key for the design of permanent magnet variable-frequency door-motor with one-driver dual control. The hardware structure of door-motor controller is shown as figure 2.
structure framework so that to form a closed-loop control system, allowing the door-motor to quickly respond to the variation of load and velocity. Man-machine interaction module has been added to guarantee the use of door-motor in various environment and convenient debugging. Voltage and current sensing have been added to protect controller and motor so that it can timely stop output to protect controller and motor in case of external overvoltage, under voltage and overcurrent.

The variable-frequency main circuit adopts intelligent power module IPM, thereby, the door-motor controller has better driver and protective function and simplifies the design of drive circuit and protective motor. Hall current sensor has been selected to detect the current signal of motor stator V phase and W phase and the U phase current has been calculated by making use of the three-phase current symmetry formula \( i_u+i_v+i_w=0 \). The detection for motor stator adopts magnetic induction encoder and PWM (Pulse-Width Modulation) drive signal obtained through control algorithm so that to control the permanent magnetic synchronous motor.

3.1. Design of some software
If the door-motor control is the brain for the whole door-motor, then, software will practically be the soul. In last chapter, hardware structure design of door-motor has been completed, in this chapter, software structure will be introduced. The whole door-motor needs to fulfill the functions including the calculation of opening and door-close velocity curve, self-positioning of permanent synchronous motor, self-learning of door width, failure detection and process, external communication. The door-motor applies to the demanding use environment of high-velocity elevator, which has higher requirement of instantaneity for the operation velocity of door-motor, therefore, the impact on efficiency of program execution for whole software framework is significant.

The door-motor control adopts processor chip TMS320F2812 with high-performance digital signal that popularized by TI. The chip has been a DPS developed aiming at digital control and has been mainly applied to built-in control. TMS 320F2812CPU is equipped with 32-bit fixed point micro control unit (MCU) and a basic frequency as high as 150MHz (6.67ns periodic time). The internal integration consists of ample resources \([7]\) such as PWM module, AD module, multiple timers, serial communication module, input capture module and output comparison module.

1) The control of opening and closing velocity
The main function of elevator door-motor control system is the movement of opening and closing the door. It is requested to have a graceful and smooth transition of door-motor running, short opening and closing time and efficient running in the design, therefore, the door-motor controller needs to have a velocity switching curve with excellent performance.

A dual closed-loop structure of velocity and current has been adopted to achieve the graceful operation curve. The vector control principle is shown as Figure 3.

**Figure 3.** Vector control system schematic diagram for permanent magnet synchronous motor
Velocity is the external loop, the given velocity is compared with the feedback velocity and the given value of stator quadrature axis component iq will be obtained by PI regulating the difference value. Current is the internal loop, meanwhile, it is a dual loop structure, the given value will be respectively compared with the feedback current value of Clark transformation and Park transformation and then, after the Park inverse transformation, the alternating and direct axis components (Uq and Ud) of the output voltage are calculated, and then the duty ratio of PWM is calculated through Space Vector Pulse Width Modulation (SVPWM) Modulation so as to control the output voltage of the inverter. In order to realize the velocity governing operation, the value of PWM comparison register needs to be calculated by PID debugging module. All algorithms will be operated at a frequency of 20 KHz and PWM duty ratio will be refreshed in every PWM cycle. The second motor will repeat the same process, then, the complete control of dual-motor drive provided by single DSP controller can be realized.

2) The leaning of motor orientation angle

There will be deviation in actual assembling process for permanent magnet synchronous motor. It is difficult to make sure the same orientation angle for every permanent magnet synchronous motor, therefore, it is required to learn the positioning of orientation angle [8]. If the deviation of orientation angle for rotor is too big, then, it will not only cause door bump because of the large output current of motor and powerless output, but also severely affect the subsequent calculation of rotor position, as a result, it will not be able to correctly complete other serial algorithms related to motor control and will cause disordered operation and make the regular operation impossible. Therefore, the accurate orientation angle is the essential guarantee of reliable start of motor. It is necessary to design a set of rapid and effective mechanism to obtain orientation angle of each matched motor.

The positioning of the motor in this design adopts magnetic positioning method, which is to rotate the rotor to a known position through force start. The initial positioning information of rotor can be obtained by the direction of rotation of rotor when the is current vector is charged to motor rotor.

Permanent magnet variable-frequency door-motor with one-driver dual control adopts one controller to simultaneously control dual-motor, both motors will be connected by synchronous belt. If orientation angle self-learning is carried out at the same time, the two motors will bear forces on each other through the synchronous belt, resulting in a large deviation of orientation angle, as a result, the operating performance will decline. The solution is to conduct self-learning of orientation angle respectively for motor A and motor B through controller, the value of orientation angle is readable, beyond that, its accuracy can be verified by controlling the single motor to operate.

3.2. The cooperative work and switchover of dual-motor

TMS320F2812 has two event management modules (EVA,EVB), including timers, full comparison PWM unit, supplementary capture unit and four-quadrant encoder circuit, which can be applied to the application of dynamic control and motor control. These two event management modules have same periphery and are able to simultaneously control 2 set of three-phase motor. All these features enable to fully suffice the function requirements for synchronous control system of dual-motor.

Dual-motor will be controlled by single DSP digital chip to simultaneously output PWM signal, after the signals are amplified, they will be input into the IPM driver module of the dual-motor respectively. The encoder pulse signals of each motor will feedback to the DSP respectively. After the calculation and processing of the software, the synchronous operation of the dual-motor will be controlled. R141 and R142 are respectively the sampling resistances that detected by current of 50mΩ/1W for V phase and W phase of the motor. The series connection in the circuit is to facilitate the current into a voltage signal for measurement.

In software processing, compared with the door-motor controller controlling one motor, the software of dual-motor controller needs to simultaneously process the information sampling, processing and output for two motors. The software adopts modular compiling, so, many function modules are needed to call twice. During the major loop, the timer interrupt service program periodically generates an interrupt that result in the program to start executing the control. In timer interrupt service program, the closed-loop control of current loop and velocity loop will be completed by detecting the output voltage,
reading output revolving velocity with encoder port circuit and gathering. According to the actual velocity of the motor output, the closed-loop control quantity of the single-axis position is output to the motor driver through PID calculation. The actual velocity of output axis of two motors can be obtained by calculating their actual position. According to the actual velocity of output axis for two motors, the velocity difference and position difference will be obtained. And then, input these differences to the cross-coupling control program module to process, then, the cross-coupling controlled quantity will be obtained. The cross-coupling controlled quantity is added or subtracted from the closed-loop controlled quantity of single axis position, and then output to the motor driver to realize the cross-coupling synchronous control of two motors, so as to obtain good synchronization control accuracy.

In double inverter driver, failure management needs to be paid more attention. The traditional DSP controller that controlled single inverter normally consists of simplex failure management system; it will shut down the controller if failure occurs. The double inverter controller requires to equip specialized signal-receiving pin of failure detection for each motor. A certain quantity pin will be taken to respectively correspond to overvoltage, overcurrent and encoder signal for each motor of these two motors. Few pins corresponding to single motor will be jointly connected to one logic or module, when any of them occurs the change from low to high or from high to low, it will interrupt and the PWM output of corresponding motor will be shut down, at this moment, the motor that has been shut down will be at free state as a driven axis. The maximum operation velocity of the motor output is controlled by limiting the given velocity of the working motor so as to reach the state of slow opening and closing, which reminding the user that the door-motor is now in single motor failure protective state and it is required to be inspected for troubleshooting.

4. The model selection of permanent magnet synchronous motor

The permanent magnet synchronous motor selected is the one that has been specially produced for door-motor drive by some manufacturer. Please check table 1 for motor parameters.

| Parameter name     | Parameter value | Parameter name      | Parameter value |
|--------------------|-----------------|---------------------|-----------------|
| Rated power        | 200W            | Pole pairs          | 4               |
| Rated voltage      | 125V            | Insulation grade    | F               |
| Rated current      | 1.6A            | Diameter of pulley  | 56mm            |
| Rated torque       | 8.5N*m          | Rated velocity      | 225r/min        |
| Rated frequency    | 15hz            | Working system      | S3on6Soff9S     |

The permanent magnet synchronous motor and magnetic encoder are integrated at the rear end cover of the motor and introduced by the outgoing line from the side of the motor. The motor adopts rectangular structure, which is easy to install and fix. A heat dissipation slot is designed on the main case.

5. The mechanical design of door-motor

The adoption of bilateral symmetric structure of the permanent magnet variable-frequency door-motor with one-driver dual control is to balance the weight of elevator car for left and right side and prevent operation with unbalance loading. The door-motor controller is designed at the top of the door to the right so that the debugging and maintenance personnel can come in and go out of the car roof. The side surface is dominated by flat design, which will expand the space for people standing on the car roof by reducing the thickness of side surface and make the installation easier for these personnel.

The design of permanent magnet variable-frequency door-motor with one-driver dual control adopts the center dividing structure, the net thickness when opening the door is 800mm-1400mm and height is 2100mm-3000mm, which will be able to cover most of the high-velocity elevator car design. The mechanical design is as shown in figure 5.
Figure 4. The mechanical design drawing for the permanent magnet variable-frequency door-motor with one-driver dual control

The door-motor adopts a door-motor controller to drive two permanent magnet synchronous motors with synchronous belt wheels and these two synchronous motors are connected with synchronous belt, which is directly connected with door strap module so as to drive the door plank of elevator car. The door plank module of each elevator car is directly connected with anti-pushed asynchronous door knife and will be synchronously operated with door plank. Through the operation of the door knife to drive the door holder on the door lock so that the door of elevator car and the landing door do horizontal opening movement. It has same process to close the door, so, we will not bore you with details here.

The light curtain signal power supply installed on the door plank of the elevator car is connected with the connection box on top of car through narrow belts. The reason to use flat cable is to prevent the damage of light curtain signal line from millions of opening and closing impact as well as the wind pressure born on the car roof in high-velocity operation.

6. Experiment and results analysis
A testing prototype has been assembled according to overall plan in the testing center. The prototype adopts center dividing structure and the width OP=1400mm, height HH=2400mm, consisting of a set of elevator car system, a set of landing door system and the total weight is as heavy as 320kgs, which suffices to the design requirements.

In order to verify whether the design is successful, the door-motor operation curve adopts PMT and EVA-625 vibration analysis tool software for measuring and analysis. Noise, velocity, distance, acceleration and rate of acceleration change can be collected and analysed, and the vibration and noise that felt by the human body can be accurately reflected.
Figure 5. The opening and closing curve of door-motor under dual-motor operation

The horizontal axis refers to time axis with the second as unit and the vertical axis refers to the velocity with the m/s as unit. The first half is the operation velocity curve when the door is closing and the latter half is the operation velocity while the door is opening. The time to close the door is 2.4S and open the door is 1.9S, which suffice the input requirements in initial design. The maximum velocity to open the door is 750mm/s, the designed maximum velocity to close the door is 550mm/s.

When fault has occurred on one of the motors, it will be automatically switched to the state of single motor operation, at this moment, the maximum operation velocity will be limited to as high as 400mm/s. By reducing the velocity of opening and closing and extending the operation distance at low speed during the closing stage so that to slow down and prevent stall and bump the door.

Compared with the theoretical opening and closing curve, the actual curve of dual-motor operation will suffice the requirement of theoretical curve. The acceleration and deceleration are stable and the transition is smooth.

7. Conclusion

The permanent magnet variable-frequency door-motor with one-driver dual control differentiates itself from the traditional one lies in:

The door-motor adopts the control method with one-driver dual control, which is to directly control two permanent magnet synchronous motor with one door-motor controller. It also adopts the full vector closed-loop control, as a result, the velocity in opening and closing the door is high and the operation is stable, and it will not dump the door, which enables the high-velocity elevator to realize the efficient flow management so as to reduce waiting time for users.

It adopts the magnetic induction encoder with high reliability and SPI (Serial Peripheral Interface) communication method between controllers. The accuracy is 4096 pulse. The one-piece design of magnetic induction encoder and permanent magnet synchronous motor curbs the influence of dust, temperature and humidity in the elevator shaft so that improve the reliability.
It adopts cross-coupling control, solving the consistency of two permanent magnet synchronous motor drive so that the performance is stable, efficient, which suffice the requirements of high efficiency and stability of high-speed elevator.

When fault has occurred on one of the motors, it will be automatically switched to the state of single motor operation, which will improve the system stability by reducing elevator-stopping failure.

It has the automatic reset function if it is interrupted. If the encoder is disturbed or the input voltage is unstable, the door-motor controller will report a failure, which can automatically try to reset after 3S interval and have the failure recorded.

It adopts the structure with double door knife. Each landing door will be driven by door knife, which makes the operation more stable and meanwhile, it reduces the load intensity of single blade and the noise caused by transmission of steel wire rope.

The landing door device adopts the structure with double-layer door lock, which significantly increase the safety of high-velocity elevator. The door plank adopts the double-layer and doughnut shape-like structure, which effectively avoid the impact of wind pressure.

The innovation points of the research lie in: It is the first one in domestic that adopts one door-motor controller that simultaneously control two permanent magnet synchronous motor, which not only has the design of dual-motor with double door knife, but also has the redundant design functions such as simultaneous operation of dual-motor to improve efficiency, and automatic switchover for failure. Compared with ordinary door-motor, the time for opening and closing has significantly shortened, which distinctly improve the service efficiency of high-velocity elevator, in addition to that, it makes the operation curve of door-motor more graceful, quieter, more stable and safer.

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