Design of S-curve Direct Landing Position Control System for Elevator Using Microcontroller

Tou Wai Kei, Vai Mang I, and Cheang Sek Un

***Abstract* — This paper discusses the design of the motion pattern generator used for elevator vertical movements. A typical S-Curve like pattern generator dedicated to be used on microcontroller-based system is proposed. Pattern can be easily optimized to various needs by changing the acceleration and jerk setting. It features in direct landing of the elevator cabin and precise position correction. The performance specification, uncertainties in the realistic case and constraints of designing an elevator motion controller when using microcontroller are also introduced. An elevator motion controller using a mid-end microcontroller is implemented using the discussed new pattern generator to verify the design. Simulation and experimental results have shown that the proposed pattern generator is robust to disturbance and can meet the specification.**

***Index Terms*—Elevators, Motion Control, Motion Pattern Generator, Microcontroller, S-Curve**

I. INTRODUCTION

The developments of microelectronics makes huge contributions to elevator controller: starting from the pure mechanical-based relay-timer controller, to programmable logic controller (PLC), and even FPGA (Field-Programmable Gate Array). The performance and comfort of riding are improved with the evolution of hardware generation. During the age before microcontroller is introduced, the performance of elevators is very poor. The speed control is done by switching load resistor series to the motor using timing circuitry [1]. Moreover, the landing is performed by creeping slowly when the car approaches the door. The feeling of vibration and terrifying acceleration/deceleration greatly reduces the comfort of riding an elevator. In addition, those imperfections also give shocks to mechanical parts and shorten their life. After the bloom of programmable devices, many complex algorithms to the motion control can be implemented. The microcontroller is one of the most cost-effective and powerful solution to elevator motion controllers, not only because it can handle real-time computation, but also recently many microcontrollers provide mixed-signal processing capability and various types of peripheral devices integrated. This can greatly simplify and increase the flexibility when designing the elevator controller.

The S-Curve is one of the famous motion patterns used in elevator controllers [1]-[3]. It provides soft starting and stopping motion by gently increasing the acceleration and speed, so it increases the comfort during acceleration and deceleration. The motion stops at zero speed and zero acceleration, which can help to reduce shock and vibration to the mechanical parts. This is also known as the ‘direct landing’ feature of elevator controllers [1]. There are many approaches to generate the S-Curve pattern with direct landing [1],[3],[4], while most of them are proprietary. The precision of landing and vibration reduction is the popular topic over years in the field of elevators. However, there are many constraints when designing an S-Curve algorithm to suit the real case of elevators, for example, the motion should be stopped at any arbitrary time or position, and the maximum speed should be changed on demand during the car is running. The specification and constraints of designing an elevator controller will be discussed in Chapter 2. In Chapter 3, the proposed pattern generator will be introduced. Simulation and experiment results will be reported in Chapter 4. A method to improve landing accuracy will be introduced in Chapter 5.

II. DESIGN CONSTRAINTS

In the real elevator system, there are many uncertainties introduced into the control system such as the imperfection of the motor, the hoist way structure, the elevator cabin, the steel rope, aging of equipments, quality of maintenance and other non-ideal factors over the entire mechanical infrastructure. The motion algorithm should be able to resist those uncertainties. It is not easy to model the whole system with consideration of all those disturbance factors. Yet, it is not practical to model and take them into account when implementing the algorithm in a performance-limited CPU such as a microcontroller.

Besides, to those mechanical constraints, there are some other constraints about the control logics. In an elevator controller, there are many I/O signal feedback from many places around the building. For example, the shaft limit signal will trigger the system to decelerate the car rapidly to prevent hitting the terminal of shaft. The system must respond to those signals immediately once upon they are active. Hence the algorithm should be able to deal with destination position changing and speed pattern updating 'on-the-go' in order to respond to them at any time when the car is moving. Moreover, the acceleration and deceleration pattern could be asymmetric, which means that the time to accelerate could be different to the decelerating time. The maximum speed, acceleration and jerk should be limited under certain magnitude in order to prevent exerting too much gravity to

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This work was supported financially and technically by Innotek Technology Company Limited (Macau).

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passengers. In addition, the algorithm should be able to generate motion patterns at different maximum speed.

Although many pure mathematic algorithms provide very good tracking capability and stability [2],[5], usually they cannot fulfill those criteria of logic control above. Moreover, some designs which employ PID-based control algorithm require highly tuned gains for different situations before it can be used [4]. With consideration of those constraints, a simple but versatile S-Curve pattern generator is designed.

III. PATTERN GENERATOR FOR DIRECT LANDING

Direct landing is one of the featured functions of modern elevator controllers. With direct landing, the transportation efficiency of the elevator can be greatly increased. It can also help to improve comfort of riding and reduce shocks to mechanical parts. However, direct landing requires a precise and accurate positioning system which can resolve position in the degree of 0.1mm or smaller. Relative rotary encoder (Fig. 1) attached to the motor shaft is usually used as the position sensor. Although absolute rotary encoder may be used to provide a better positioning ability, the cost of installation and maintenance is high.

Fig. 1. Photo of a relative rotary encoder.

In our design, a rotary encoder of 2048 count per revolution is used and is attached on the motor shaft.

The proposed pattern generator is a speed pattern generator. This speed pattern is coupled to the reference speed input of the VVVF driver of the motor. (Fig .2)

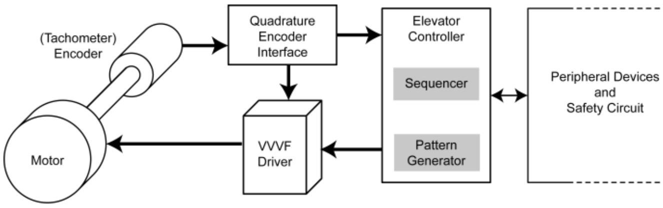

Fig. 2. Block diagram of the proposed elevator controller. Note that there are 2 feedback loops including the speed-regulation loop with the VVVF driver as the controller, the position-regulation loop with the proposed elevator controller as the controller.

It is critical to control the position of the elevator cabin precisely when it is landing (i.e.: decelerating). During acceleration and maximum speed running state, the position accuracy is not important over the speed regulation. Hence, to simplify the control algorithm, open-loop time-based control is applied during acceleration and maximum speed state. In the proposed system, the reference speed pattern is generated based on initial jerk of acceleration j_1, the maximum acceleration a_{amax}, the final jerk of acceleration j_2 and the maximum speed v_{max}. With those values set up, the S-curve pattern can be simply generated by a state machine and the speed is obtained by integrating the preset jerk value over the time. (Fig. 3)

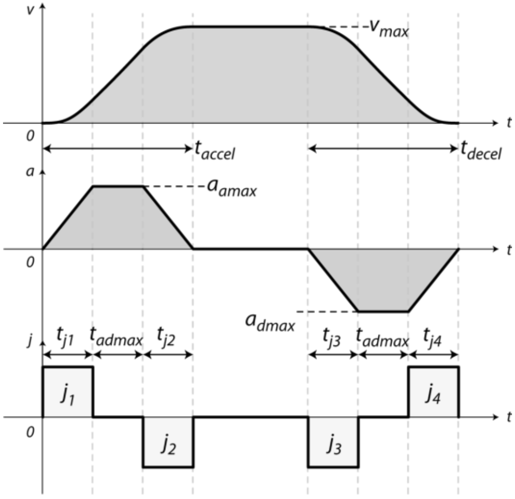

Fig. 3. The S-curve speed pattern of the elevator movement.

Users can adjust the performance (transportation efficiency) and conformability by changing the magnitude of these values. Particularly, the maximum acceleration should be kept under 0.7m/s^2 and the jerk should be kept under 1.5m/s^3 in order not to cause too heavy lifting force to passengers [1]. The maximum speed of the elevator depends on the maximum revolution speed of the motor and the capability of other mechanical parts of the system.

As a reference the time of acceleration can be calculated as

$$t_{accel} = \frac{v_{max}}{a_{amax}} - \frac{a_{amax}}{2j_1} - \frac{a_{amax}}{2j_2} + \frac{{a_{amax}}^2}{2j_1} + \frac{{a_{amax}}^2}{2j_2} \tag{1}$$

The close-loop control keeps tracking the distance between the current car position and the destination position, and then it tries to slow down the car by a linear decreasing acceleration rate (i.e. the final jerk of deceleration). In the ideal case, the speed and acceleration will both become zero as the position error becomes zero. Thus the car lands smoothly.

The brake displacement should be calculated once the elevator goes into a running state (moving state). It is because the elevator operation system (or the call scheduler) should be informed with the possible nearest position where the car can stop, thus it can respond to the calls. Otherwise, the operation system should skip calls within the brake displacement as the car cannot stop to the desired position.

In this proposed system, the direct landing pattern is an S-curve pattern regulated by the maximum deceleration a_{dmax}, initial jerk during deceleration j_3 and final jerk during deceleration j_4. The brake displacement s_{bk} can be calculated by the following equations:

$$v_{maxnew} = v_0 - \frac{{a_0}^2}{2j_3};$$

$$\Delta v_{j3} = \frac{{a_{dmax}}^2}{2j_3};\ \Delta v_{j4} = \frac{{a_{dmax}}^2}{2j_4};$$

$$\Delta v_{admax} = v_{maxnew} - \Delta v_{j4} - \Delta v_{j4};$$

$$t_{admax} = \frac{\Delta v_{admax}}{|a_{dmax}|};\varepsilon = \frac{v_{maxnew}}{\Delta v_{j3} + \Delta v_{j4}};$$

$$s_{bk1} = \frac{{a_0}^3}{3{j_3}^2} + \frac{v_0 a_0}{|j_3|};$$

$$s_{bk2} = \frac{v_{maxnew} a_{dmax} \sqrt{\varepsilon}}{|j_3|} - \frac{{v_{maxnew}}^3 \sqrt{\varepsilon^3}}{6{j_3}^2};$$

$$s_{bk3} = t_{admax} \Delta v_{j4} + \frac{\Delta v_{admax} t_{admax}}{2};$$

$$s_{bk4} = \frac{{a_{dmax}}^3 \sqrt{\varepsilon^3}}{6{j_4}^2};$$

$$s_{bk} = s_{bk1} + s_{bk2} + s_{bk3} + s_{bk4} \quad (2)$$

Obviously, the brake displacement depends on all the control parameters of the pattern generator (v_{max}, j_3, a_{dmax}, and j_4), the current speed v_0, the current acceleration a_0 and the current jerk j_0 of the elevator. A rapid landing pattern leads to a shorter brake displacement and a smooth landing pattern leads to a longer brake displacement.

In deceleration, right after the maximum deceleration reaches, the system will switch the open-loop motion control to close-loop motion control mode (Fig. 2 time range t_{admax} and t_{j4}). Acceleration is regulated and the speed pattern is generated by integrating the real-time calculated acceleration. At this state, the acceleration set-point $a_{setpoint}$ is updated in every 5ms with the following formula:

$$a_{setpoint} = \frac{2{v_0}^2}{3(s_{dest} - s_0)} \quad (3)$$

where s_0 and s_{dest} are the current position and the destination position.

The simulation result of the proposed system is introduced below. The motion of a long run of 7 floors (approximately 27 meters) with maximum linear speed of 2.5m/s is simulated. Details of parameters of the motion profile setup are stated in Table 1 below.

TABLE 1. MOTION PROFILE OF LONG RUN

Initial Position	**15549.88 mm**
Destination Position	**42499.00 mm**
Maximum Linear Speed	**2500 mm/s**
Jerk 1 j_1	**750 mm/s^3**
Maximum Acceleration a_{amax}	**750 mm/s^2**
Jerk 2 j_2	**750 mm/s^3**
Jerk 3 j_3	**750 mm/s^3**
Maximum Deceleration a_{dmax}	**825 mm/s^2**
Jerk 4 j_4	**450 mm/s^3**

A smooth and continuous velocity curve is generated by the proposed design (Fig. 4 and Fig. 5). Generally, the landing position error is acceptable within 0.6mm. Simulation result has shown that the error is almost zero and the proposed design can achieve this criterion with a wide range of scenarios.

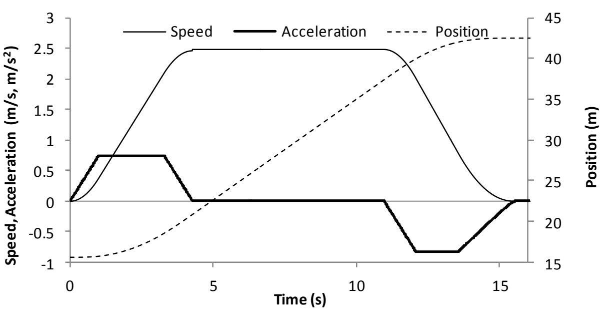

Fig. 4. Simulation result of long run.

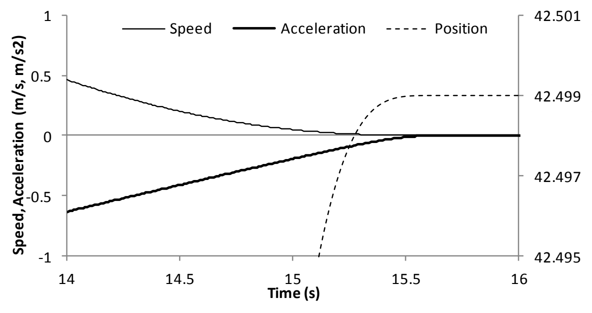

Fig. 5. Simulation result of long run. (Zoomed to landing section)

IV. HARDWARE DESIGN

In order to prove the design, a hardware elevator controller is designed. It is composed of Microchip dsPIC30F6010A which is a microcontroller with DSP embedded. For the sake of high precision, all control values are calculated inside the DSP based on 32-bit floating point data type. The control values are updated in every 5ms. The state machine to generate the S-curve and the safety monitor are also running inside this microcontroller. The proposed elevator controller is then installed in an elevator test tower and its specification is stated in Table 2.

TABLE 2. SPECIFICATION OF THE TEST TOWER

Tower	
Number of door zone	**26**
Total height	**76 meters**
Mechanical System	
Motor type	**Gearless**
Rope ratio	**1:2**
Motor speed	**217 rpm**
Linear speed	**2.50 m/s**
Maximum cabin load	**1300 kg (16 persons)**
Motor Rated Voltage	**380 VAC**
Motor Power	**22 kVA**
Electrical System	
Motor Driver	**Siei ART-Drive ARy**
Encoder resolution	**2048 count per revolution**
Speed Reference Signal	**0-10V**

In order to compare between simulation and experimental results, the same configuration is used for both tests. Through the experimental result, the proposed design was proven to have good tracking as the simulation result in most of the aspects. (Fig. 6 and Fig. 7)

The experiment has also shown that the proposed design can achieve almost zero landing error with no more than 0.2 second of extra landing time compared to the simulation result. It has to be noticed that even the acceleration during landing is not very smooth compared to simulation; it gives slight hit to the speed and position smoothness. Both simulation and experimental results have

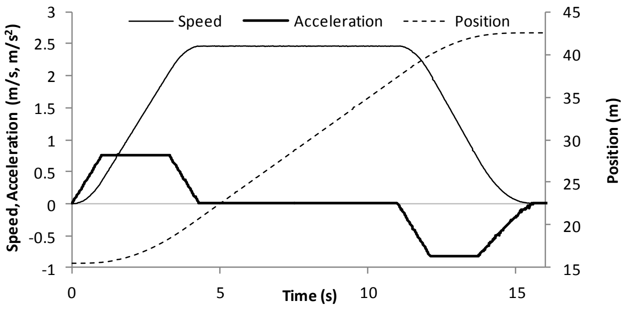

Fig. 6. Experimental result of long run.

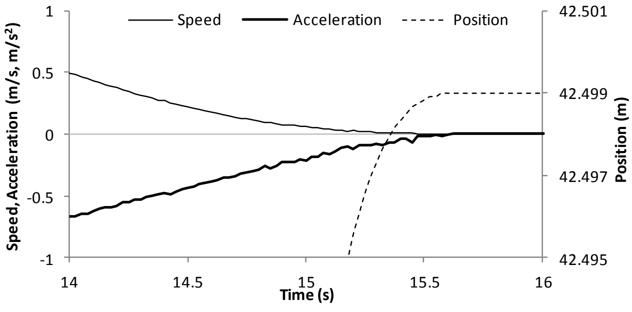

Fig. 7. Experimental result of long run. (Zoomed to landing section)

shown that proposed design can land to door zone accurately and stop at zero speed and acceleration, which is the criterion of direct-landing.

V. POSITION ADJUSTMENT

There are many reasons to install a rotary encoder only on the main shaft of the motor. First, the motor drivers (usually a VVVF driver in a modern system) need to sense the rotation speed of the motor like the control loop shown in Fig. 2. An angular speed sensing device is used, which is actually the rotary encoder. Second, the cost of an absolute rotary encoder with all its accessory parts and installation is high. Moreover, when there is no absolute encoder to be used (due to mechanical limitations), all encoders can only be treated as relative position feedback no matter it is installed on the main shaft of the motor or the speed governor. Rope slip during car running cannot be detected by the control system, especially during acceleration and maximum speed with high cabin load.

Even though the motion control system can trace the speed and position very well, due to the limitation of mechanical structure, the position of the car is always sensed as a relative value. Even the encoder reads out that the cabin land without errors, the rope slip may make the car cabin land millimeters far away from the floor level as seen inside the cabin. In this proposed design, extra digital feedback signals are used in order to cancel the errors due to rope slip.

By the regulation in some countries [10], doors can only be opened when the car cabin is within door zone. It is necessary to install 2 sensors on each door zone in the lift shaft. They are usually 20-30cm apart. The door can only be opened when these 2 sensors are detected. As these 2 sensors are fixed onto an independent rail along the lift shaft, it can be used as absolute position indicators.

The elevator should run a trial run before it can be used. In this trial run, the position of these sensors on each floor (door zone) is recorded. After the trial run, the car cabin position can be adjusted with the learnt position value when the car cabin flies by them. However, since the position adjustment will explicitly update the position of the car cabin, it will disturb the control loop when the car is decelerating. With the proposed direct landing control method, experimental results of this disturbance is shown in Fig. 8 below.

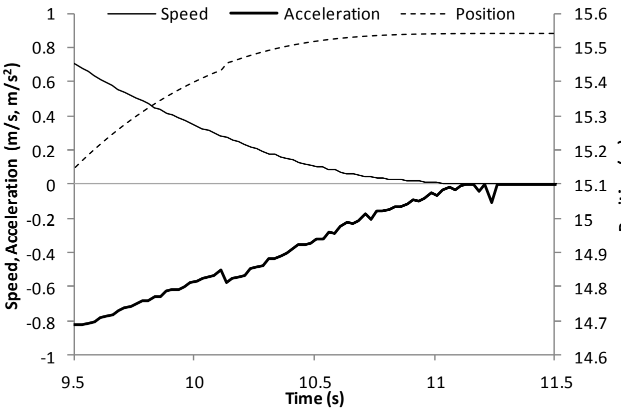

Fig. 8. Tracking ability of the proposed system under disturbance of forced position adjustment.

In Fig. 8, position adjustment happens at around 10.2 second. According to Equation 3 the acceleration has an immediately step response to compensate the position difference. Though this, the speed curve still maintain a smooth decay trend.

As the position adjustment usually takes place when the car is at very low speed (<0.5m/s), a step change on the acceleration regulation curve does not cause too much vibration to the passenger. The speed curve is still smooth. Moreover, in most of the cases, the position adjustment is in the range of no more than 2cm. The discontinuity of acceleration is acceptable. The proposed direct landing algorithm also responds to this step change with a converge trend.

VI. CONCLUSION

In this project, a control system for elevator featuring direct landing is proposed. The control system is a speed regulator by implementing S-curve control algorithm. The proposed design is tested by using a microcontroller. Both the simulation result and experiment result show that the design provided very good performance and tracing ability to resist disturbance. Moreover, to improve landing accuracy, position adjustment is introduced by making use of the door zone sensor in the lift shaft.

REFERENCES

[1] G. R. Strakosch, *The vertical transportation handbook*, New York, Wiley, 1998.

[2] J. Li, D. Niemann, H.0. Wang, "Robust Tracking for High-Rise / High-Speed Elevators," *Proceedings of the American Control Conference Philadelphia, Pennsylvania June 1998*, pp. 3445-3449.

[3] J. Pasanen, O. Vainio, H. Tenhunen, P. Jahkonen, S. J. Ovaska, "An ASIC Digital Motion Control Unit," *ASIC Seminar and Exhibit, 1990. Proceedings., Third Annual IEEE*, pp.7/2.1-7/2.4.

[4] H. Ryu, S. Sul, "Position Control for Direct Landing of Elevator using Time-based Position Pattern Generation," *Industry Applications Conference, 2002. 37th IAS Annual Meeting. Conference Record of the*, pp. 644-649.

[5] Y. Lee J. Kang and S. Sul, "Acceleration Feedback Control Strategy for Improving Riding Quality of Elevator System," *Industry Applications Conference, 1999. Thirty-Fourth IAS Annual Meeting. Conference Record of the 1999 IEEE*, pp. 1375-1379.

[6] X. Yang, Q. Zhu, H. Xu, "Design and Practice of an Elevator Control System Based on PLC," *2008 Workshop on Power Electronics and Intelligent Transportation System*, pp. 94-99.

[7] O. V. Beldiman, H. 0. Wang, L. G. Bushnell, "Trajectory Generation of High-Rise/High-Speed Elevators," *Proceedings of the American Control Conference Philadelphia, Pennsylvania June 1998*, pp. 3455-3459.

[8] R. Roberts, "Control of high-rise high-speed elevators," *Proceedings of the American Control Conference Philadelphia, Pennsylvania June 1998*, pp. 3440-3444.

[9] Q. Hu, Q. Guo, D. Yu, J. Lili, "A Novel Adaptive Control of Elevator Motion System," *Proceedings of the 6th World Congress on Intelligent Control and Automation, June 21 - 23, 2006, Dalian, China*, pp. 2007-2010.

[10] *BS EN 81-1:1998 Safety rules for the construction and installation of lifts. Electric lifts*, London, British Standards Institution.