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Digital distance control system research and implementation

Qian Yi-bin*, Wu Xiao-jie, Liu Xiang-chao

China University of Mining & Technology, Xuzhou 221116, China

Abstract

The paper introduced a mathematical model of three segment speed reference in main shaft hoist system, and an application of equivalent area method to control shaft hoist shut-down precisely using three segment speed reference curve. In order to verify the correctness of the theory, we established a MATLAB model. From mathematical analysis and computer simulation, we can see that this control approach is feasible.

Keywords: digital stroke control system; MATLAB; simulate

1. Foreword

Mine hoist takes charge of the lift of minerals and the delivery of staff, materials and equipment in mine. The technical performance of electronic control device affects the efficiency and security of mine production directly. With the development of coal production and the increase of production capacity, in part of our mines, hoist systems have already been the bottle-neck of mine production. The insufficient lift capacity almost becomes the common problem in mine production. One of the reasons causing this situation is the inefficiency of hoist system. Therefore, how to optimize hoist control system, raise the efficiency, extend equipment life, and make hoists run safely and efficiently is an important question for discussion, and also the main purpose of investigating the digital distance controller of hoist. We investigated the S-velocity curve and simulated it using MATLAB/ SIMULINK. This control method has already been successfully applied to the mine hoist system.

2. Model of three segment speed reference

The electric transmission system of mine hoist is in essence a position control system. The acceleration, deceleration, creep and shut-down of mine hoist in shaft are related to its position, that is, the speed reference of hoist also needs the position information. In the past, the distance reference was given by cam plate, but now, the electronic circuit or computer were commonly used to produce speed reference signal according to distance principle. Obviously, it is easy to produce the three segment speed reference by using computer according to distance principle.

If hoist runs normally, its maximum speed keeps at v_m, and for the speed curve it produces, we always call it three segment speed reference curve. Former curve contains segments of acceleration, uniform speed, creep and levelling; it can ensure the comfort of staff, smooth speed regulation and speed accuracy. But this pattern influences

the hoisting efficiency to some extent because it contains the creep segment. With the advances of sensor technology, the appearance of real-time control system and the improvement of monitoring system, it is possible to remove the creep and levelling segment to make hoist running efficiency optimal. Three segment speed reference curve only contains three segments: acceleration, uniform speed and deceleration, so we can improve hoisting efficiency while keep the safety.

Fig. 1 and Fig. 2 show the four segments and three segments speed reference curve, respectively. We can easily see that, the hoisting efficiency of the four segment pattern is lower than that of the three segment pattern obviously. Acceleration segment and deceleration segment of perfect three segment curve should be symmetric.
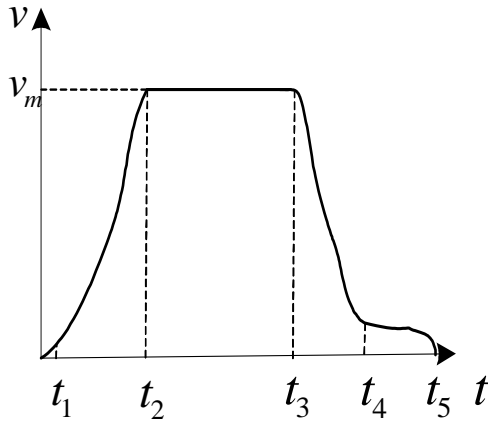

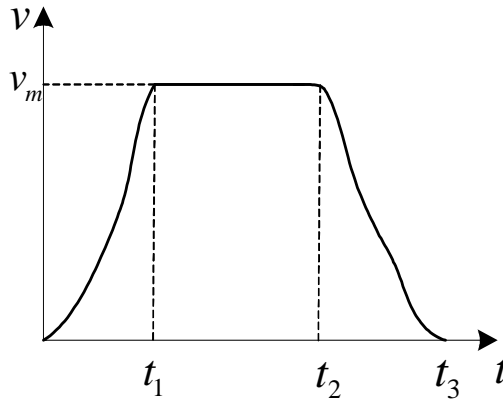Fig. 1. Four segment mode   Fig. 2. Three segment mode

The speed calculation method is the double integration of jerk. It can present actual given value over each calculation period, consequently, produce the running curve $v = f(t)$. Fig. 3 shows the principle diagram of the three segment speed reference curve, where s^* is the depth of shaft, p_1, p_2, p_3 are speed module, acceleration module, jerk module at time t_k; q_1, q_2, q_3 are three integral modules. According to these modules, we can obtain three variables s_f, v_f and a_f as given distance. The expressions below are for module p_1, p_2 and p_3. v_k^*, a_k^*, r_k^* are the given value of speed, acceleration and jerk, respectively.

$$v_k^* = \sqrt{2a_m(s_k - s_{k-1})} \qquad (1)$$

$$a_k^* = \sqrt{2r_m(v_k - v_{k-1})} \qquad (2)$$

$$r_k^* = \alpha(a_k - a_{k-1}) \qquad (3)$$

Initial value: $s_0 = v_0 = a_0 = 0$.

where,

s_k, v_k, a_k, r_k —the sampling values of distance, speed, acceleration, jerk in the kth sampling period, and k is integer beginning with 1.

s_{k-1}, v_{k-1}, a_{k-1}, r_{k-1} — the sampling values of distance, speed, acceleration, jerk in the $(k-1)$th sampling period, and k is integer beginning with 1.

a_m — rated acceleration and rated deceleration.

r_m — rated jerk.

α — proportional coefficient.

We must correct this system because when we solve expressions (1) and (2), we suppose a_m and r_m are invariable in time interval Δt, but in actual system, they are variable in the time interval of start-up, accelerating to constant–speed, constant speed to acceleration and shut-down.

Correction coefficient $k = \dfrac{\left(a_f + a_m\right)^2}{6r_m^{\ 2}} + \dfrac{a_m^{\ 3}}{24r_m^{\ 2}}$ (4)

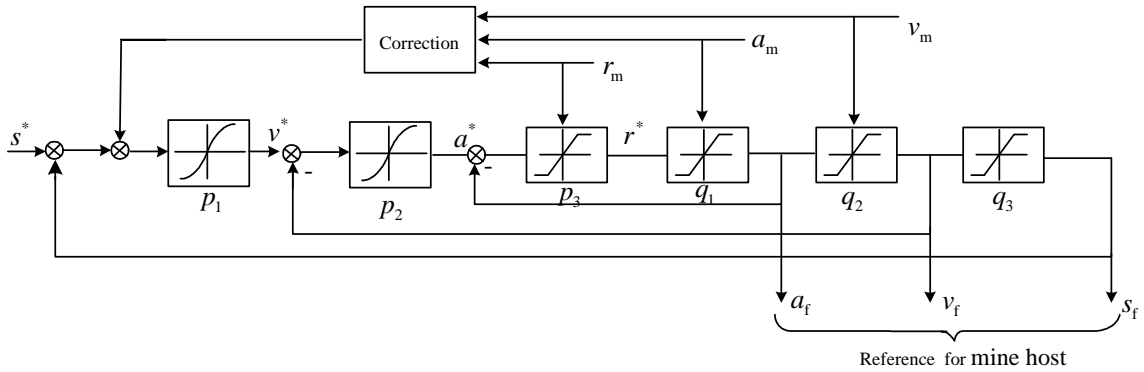a_f —Given acceleration value.

Fig. 3. Three segment principle diagram

3. MATLAB simulation of three segment speed reference curve

We simulated the three segment speed reference curve using MATLAB/SIMULINK. Fig. 4 shows the simulation block diagram.
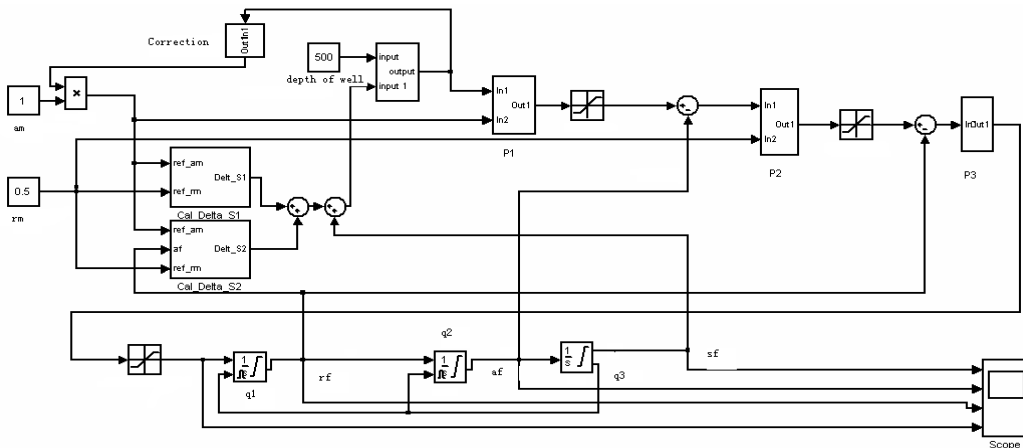

Fig. 4. Three segment curve MATLAB simulation

In this simulation, suppose that the height of shaft $s = 500\ m$; the maximum speed $v_1 = 10\ m/s$ (Fig. 5); the maximum speed $v_2 = 6\ m/s$ (Fig. 6); the rated acceleration $a_m = 1\ m/s^2$; the rated jerk $r_m = 0.5\ m/s^3$.

We can find relatively perfect dynamic response curve via simulating system. Fig. 5 and Fig. 6 show the distance curve, speed curve, acceleration curve and jerk curve from the top to the bottom. We can see from the

acceleration curve and jerk curve that the hoist shuts down accurately, and the acceleration segment and deceleration segment seem symmetrical and perfect.

Fig. 5 and Fig. 6 are given as a_m and r_m are fixed and v_m is variable. We can see the deceleration of hoist is fixed but the slowdown point varies. In practical operation, we should take account of the performances of a machine to set the best rated speed so as to greatly improve the hoisting efficiency because the higher the rating speed, the less the time it needs and the higher the hoisting efficiency is.
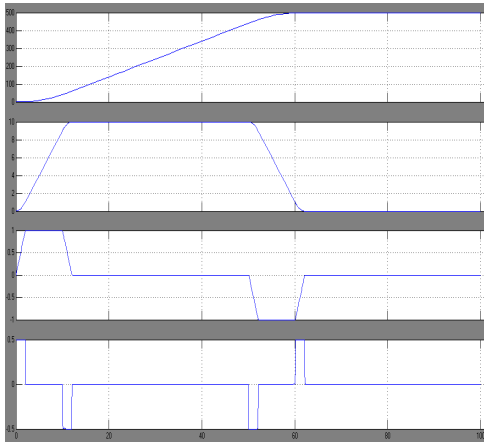

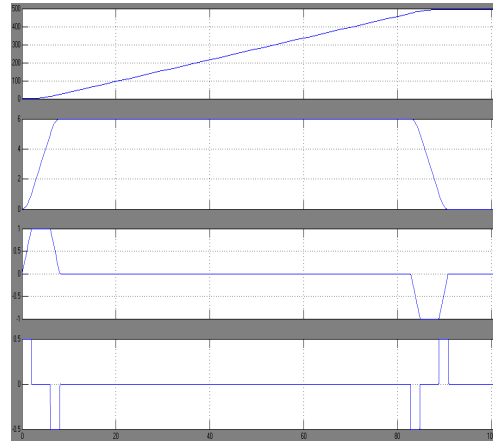Fig. 5. Simulation curve of highest speed 10 m/s

Fig. 6. Simulated curve of highest speed 6 m/s.

4. Implementation of three-segment speed reference curve

In experiment, we chose S7-300 PLC and analog output module SM332, and connected the analog output to IBA to observe output waveform. We use STEP7 to program in timing interruption called OB35 because this program applies integral operation.

Fig. 7 is the dynamic course as the speed reference changes from 5 m/s to 0 m/s then to 3 m/s. In the figure, we can see that the S-velocity curve is good; therefore, the design objective has reached.

5. Conclusions

Limiting the reference acceleration and jerk can efficiently control current rate in electromotor and thyristor, improve dynamic strain in steel rope which may appear in start-up and shut-down , and protect the circuit elements and lifting machine. The three segment speed reference curve can raise the lifting ability of mine under the premise of production safety and shut-down accuracy so as to solve the problem of lifting bottle-neck.

The model of three segment speed reference was put forward in this paper and simulation was performed using Siemens's PLC. The experiment result indicates that the curve reference of this model is right, conquers the disadvantage of outdated hoists that their distance reference curve needs a segment of creep, and improves the efficiency of mine hoisting.
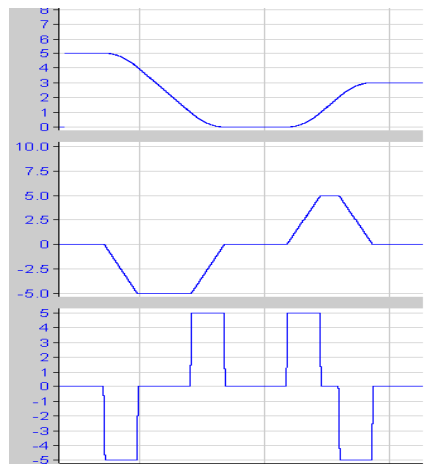

Fig. 7. Iba Analyzer observation curve

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