

## Research Article

# Expert Control of Mine Hoist Control System

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This paper presents a kind of intelligence control algorithm for the mine hoist control system. Firstly, the desired output of the system is described by a speed curve of hoisting process. Then, the structure diagram of the hoist system is constructed, and the expert PID controller is designed based on the model of this control system; the expert knowledge base was established according to the analysis of characteristics in different periods of the hoist process. Finally, the control effect was verified by SIMULINK simulation; by comparing with the result of conventional PID control, expert PID control is improved more safe and suitable for the mine hoist control system.

## 1. Introduction

Mine hoist is mainly used in coal and other mining enterprises. It is the key equipment in production and is the only channel to transport person and material in the mines. Its performance directly affects the reliability and safety of production; once it fails, not only will it seriously damage the device but also cause server casualties [1–3]. In this paper, we are concerned on the designing expert control algorithm for the mine hoist control system.

Expert control is a cross-subject of artificial intelligence and control theory. It can simulate expert intelligence in an unknown environment and realize effective control. It has been widely used in many industries and provides a new approach to solve the industrial control problem and realizes industrial process control. Chen et al. designed a supervisory expert controller for ball mill grinding circuits [4]. Shi et al. combined fuzzy PID control and the expert decision to regulate the temperature and an expert fuzzy PID controller is designed [5]. Bergh et al. used expert control in the tuning of an industrial thickener [6]. An intelligent energy-efficient outdoor lighting control system using an expert system was developed by Atis and Ekren that could be used in green buildings [7]. Bergh et al. designed a predictive expert control system for a hybrid pilot rougher flotation circuit [8]. Belle et al. designed and realized a distributed expert system on a

control strategy to manage the execution flow of rule activation [9]. Di Maio et al. designed a regional sensitivity analysis-based expert system for safety margin control [10]. Ye et al. used the expert PID to control the valve positioner [11].

Many researchers have been carrying out the research on the control of the mine hoist system and other DC speed control system; they have obtained some achievements. Hamed et al. designed a fuzzy PID controllers for real-time DC motor speed control [12, 13]. Liu et al. and Gundogdu et al. used fuzzy PID control and self-tuning PID control in the brushless DC motor system separately [14, 15]. Ma et al. designed a parameter self-tuning fuzzy PID control for DC motor [16]. Zdrozis worked on the analysis of abnormal modes of the hoisting DC electric drive system [17]. Gupta et al. analyzed the applications of artificial intelligence in permanent magnet brushless DC motor drives [18]. Emhemed and Mamat presented an overview of proportional integral control (PI) and artificial intelligent control (AI) algorithms for industrial DC motor [19]. Chang et al. modeled the nonlinear DC motor system as Takagi-Sugeno (T-S) fuzzy model [20]. Ulasayar et al. designed an intelligent speed controller for brushless DC motor (2018) [21].

All these achievements listed above will bring great help in the research in this paper. This paper adopts expert PID control in the mine hoist system, by analyzing hoisting

process in different periods. Based on experiences, expert rules are designed to regulate controller parameters to achieve desired hoist process. Compared with the simulation results of conventional PID control, it is indicated that expert PID is more suitable for mine hoisting control.

## 2. Description of Mine Hoist Control System

*2.1. Analysis of Hoisting Process.* The mine hoist system is to transport workers and materials up and down the well; both safety and comfort should be considered in the designing of the hoist control system. The hoisting process of the mine hoist system is shown in Figure 1, where  $n$  represent the rotate speed of the DC motor which is used in the hoist system. In some cases with large load and special hoisting control requirements, the acceleration stage can be further subdivided into three stages (as shown in  $t_0-t_3$ ).

The whole hoisting process divides into five stages, namely, the acceleration stage, constant stage, deceleration stage, crawling stage, and parking stage, respectively. In the acceleration stage, the speed of the DC motor accelerates from standstill to maximum speed. In the constant stage, the machine keeps running at maximum steady speed, and the constant stage is the main operational stage. The speed slows down from steady to creeping period in the deceleration stage. In the crawling stage, the container, such as cage or elevator car, is ready to locate and to brake. In parking stage, the cage reaches to the target position and then stops. The detail of each period is describes as the following paragraph.

The acceleration stage happens between moment 0 and  $t_3$  as described in Figure 1; in this stage, underground workers transfer the signal that the cage has been filled of materials to surface workers, the hoist begins to work. Due to mechanical inertia, speed increase slowly during moment 0 and  $t_1$  and then at a rapid rate during  $t_1$  and  $t_2$ , when the speed approximate to maximum, the increase rate slows down during  $t_2$  and  $t_3$ .

The constant stage happens between moment  $t_3$  and  $t_4$ ; in this stage, hoist operates at maximum speed so that the cage can steadily upgrade; it is the main stages of the process because it occupies the longest time in the hoisting process.

The deceleration stage happens between moment  $t_4$  and  $t_5$ ; when the cage is near the wellhead, hoist starts to slow down, and its deceleration rate is from slow to fast and then to slow; this is shown in Figure 1.

The crawling stage happens between moment  $t_5$  and  $t_6$ ; in this stage, the cage gets into the dump rail, and it operates slowly to eliminate the impact when parked at target location.

The parking stage happens between moment  $t_6$  and  $t_7$ , the hoist brake along with its speed decreasing from creeping speed to zero in this stage, which indicates the end of the whole process.

Of course, the operation safety should be taken into consideration while the size of speed and acceleration are determined in different stages.

*2.2. The Structure of Mine Hoist Control System.* In order to implement the hoist function described in the previous para-

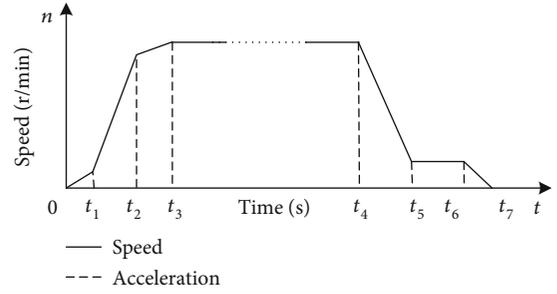


FIGURE 1: The desired hoisting process curve.

graph, we construct the control system shown as Figure 2. The closed-loop system uses a tachogenerator to measure the speed; this signal is taken as a feedback signal to compare with the reference input and the error signal is gained. The speed controller utilizes error signal as input and its output signal is taken as the control signal of the controlled object. Its task is to make the hoister work at expected speed and low overshoot. It is important for us to design a suitable control algorithm to achieve the functions mentioned above.

## 3. Design of Control Algorithm for Mine Hoist System

In the process speed regulation, the speed controller plays a leading role. The expert control algorithm can adjust the control parameters adaptively, so we use this control algorithm to decrease speed overshoot and to make the acceleration meet requirement when the mine hoist system starts working, and the expert PID algorithm is adopted finally. The input of the expert controller is the error signal between the reference and feedback signal, which is shown in Figure 2. Based on the practical situation and expert rules, control variable  $U_n^*$  and  $U_c$  are used to regulate the mine hoisting process.

*3.1. Description of Expert Control.* The expert system is a system with a large amount of expertise and experience. It makes inference and judgment according to the knowledge and experience provided by experts in a certain field and simulates the decision-making process of human experts; its main framework consists of knowledge base and reasoning mechanism. Based on the knowledge (prior experience, dynamic information, target, etc.) of control domain, it outputs appropriate control signal according to reasoning rules in a certain strategy and realizes the control function of the controlled object. The structure of expert control is shown in Figure 3.

According to the role and function that expert control plays in the control system, expert control can divide into two types: direct and indirect expert controller. In the direct expert control system, the expert system gives the control signal directly to control the working process of control object. The direct expert control system gives the control signal at each sampling time according to the measured process information and the rules in knowledge base. The indirect expert controller is an intelligent control system which is the combination of expert control and the conventional controller. The bottom layer of the system may be simple PID, fuzzy, and

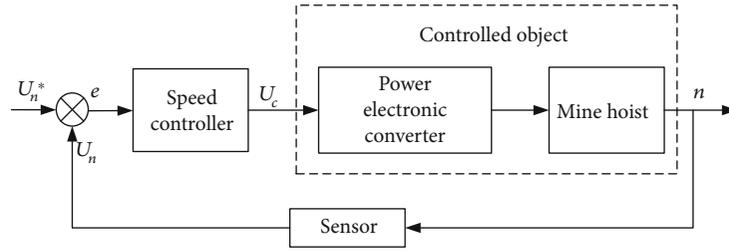


FIGURE 2: The structure diagram of the mine hoist control system.

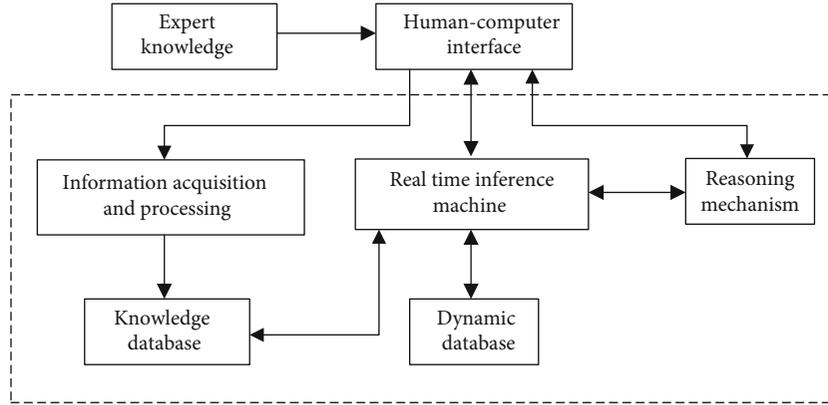


FIGURE 3: The basic structure of the expert control system.

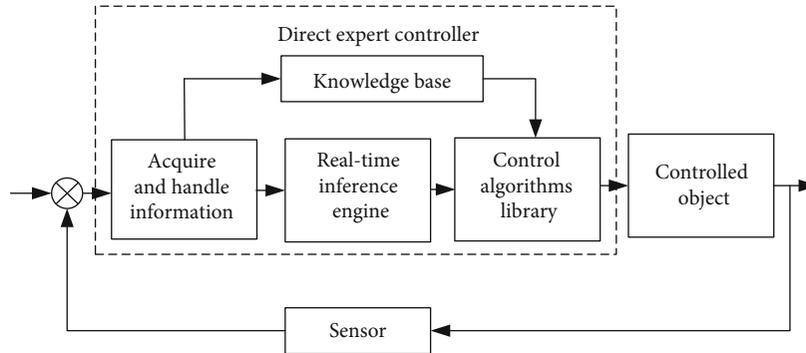


FIGURE 4: The direct expert controller.

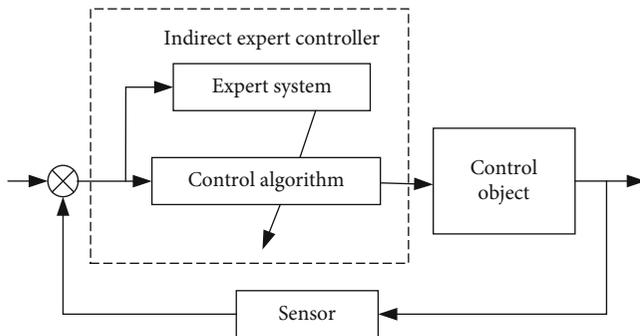
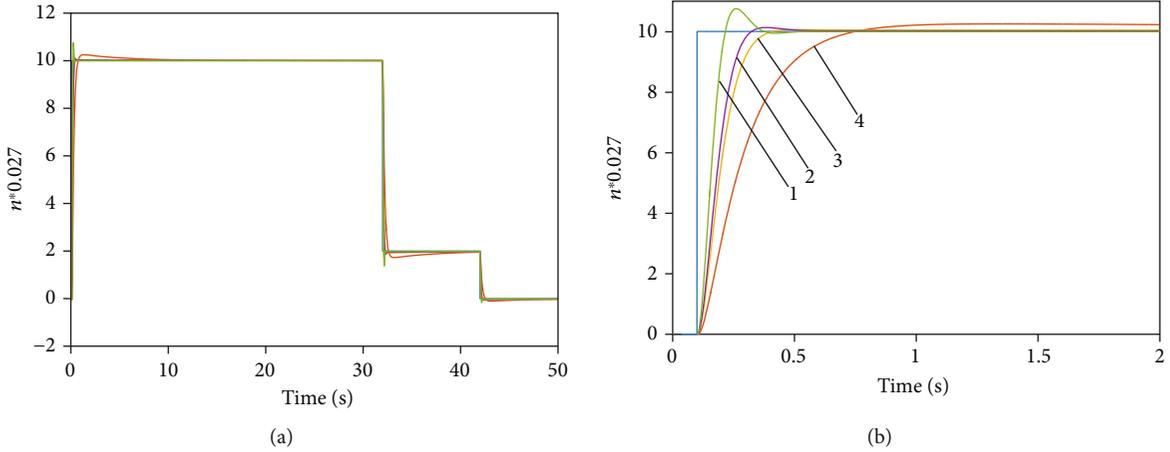
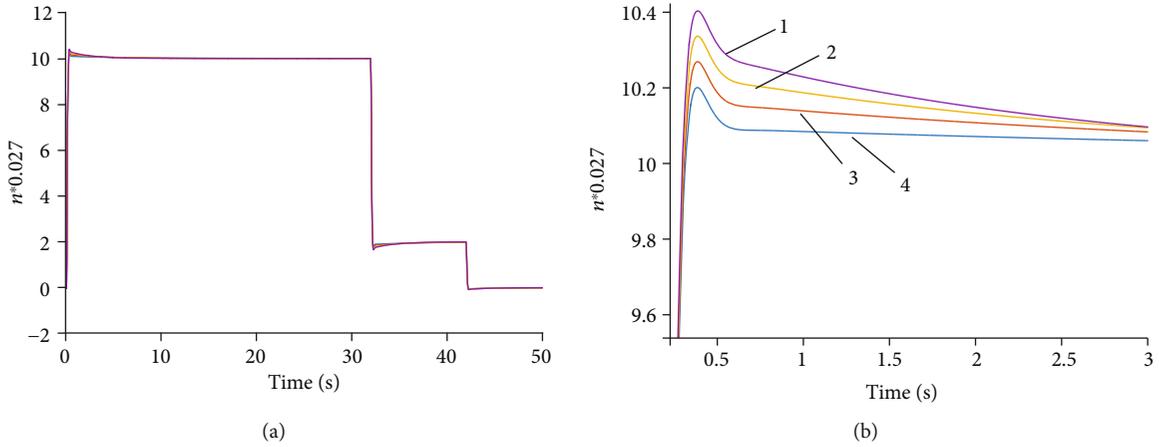


FIGURE 5: The indirect expert controller.

TABLE 1: Parameters of the system.

Parameter	Value
Nominal voltage $U_N$ (V)	750
Nominal current $I_N$ (A)	760
Nominal speed $I_N$ (r/min)	375
Electromotive force coefficient (V·r/min)	1.82
Magnification factor of the thyristor device $K_s$	75
Resistance of armature circuit $R$ ( $\Omega$ )	0.14
Time constants $T_1$ (s)	0.031
Time constants $T_m$ (s)	0.112
Feedback coefficient of speed $\alpha$	0.027
Maximum given input $U_{nm}^*$ (V)	10

\*Corresponds to the nominal speed.

FIGURE 6: Output curve with conventional PID control ( $k_i = 0.1$ ).FIGURE 7: Output curve with conventional PID control ( $k_p = 1.2$ ).

other algorithms, and expert control is used to adjust the parameters of the bottom layer algorithm. The structure of direct expert control system and indirect expert control system is shown as shown in Figures 4 and 5, respectively.

This paper chooses an expert PID controller to replace the conventional PID controller as the outer controller to control the hoist process. This controller is one kind of indirect controller. Expert control can adjust the parameters of PID controller adaptively according to the size of system deviation. The key problem of the outer controller design is to design expert control rules to improve the dynamic performance of the system at startup.

**3.2. The Design of Expert Controller.** The function of the expert controller is to make the hoisting process as shown in Figure 1. The acceleration during the start and stop process is neither too large nor too small, which will ensure both comfort and safety. The integral separation algorithm is adopted when expert rules are designed. When the error is large, open loop control is adopted, and the output of control is fixed to reduce the error quickly. When the error reduces to a certain range, PID control is adopted, and the parameters of the

TABLE 2: Response parameter of the system.

$k_i$	$k_p$	$V_{\max}$	$t_{\max}$ (s)	No. of curve
0.1	2.0	10.75	0.262	1 <sup>st</sup> in Figure 6
	1.2	10.13	0.037	2 <sup>nd</sup> in Figure 6
	1.0	10.05	0.496	3 <sup>rd</sup> in Figure 6
	0.5	10.25	1.232	4 <sup>th</sup> in Figure 6
0.2	0.12	10.4	0.388	1 <sup>st</sup> in Figure 7
0.3		10.34	0.386	2 <sup>nd</sup> in Figure 7
0.4		10.27	0.384	3 <sup>rd</sup> in Figure 7
0.5		10.2	0.386	4 <sup>th</sup> in Figure 7

\*  $V_{\max}$  is the maximum speed feedback signal.

PID controller are adjusted accordingly with the size of the error. Several related parameters need to be defined before designing rules as that is shown in the following paragraph.

Error bound  $M_1$  and  $M_2$ ,  $M_1 > M_2 > 0$ . When the error is bigger than  $M_1$ , several error threshold are defined as  $a_i$  ( $i = 1, 2, \dots, n$ ),  $a_1 > a_2 > \dots > a_n$ , the value of  $n$  is determined by the characteristics of control objectives, The output of the controller is  $b_i$  ( $i = 1, 2, \dots, n$ ) corresponding to  $a_i$ , When the

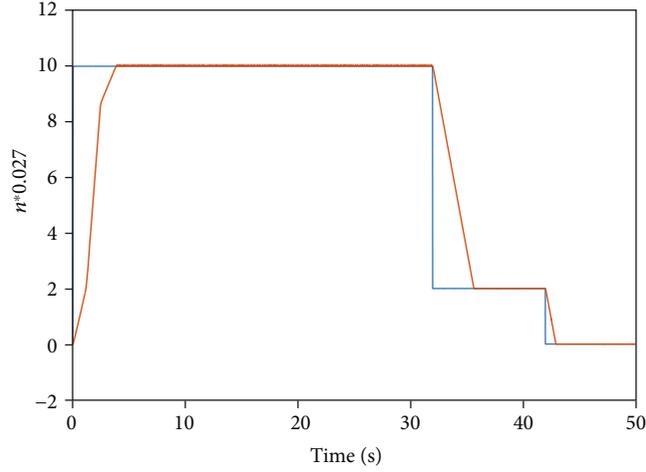
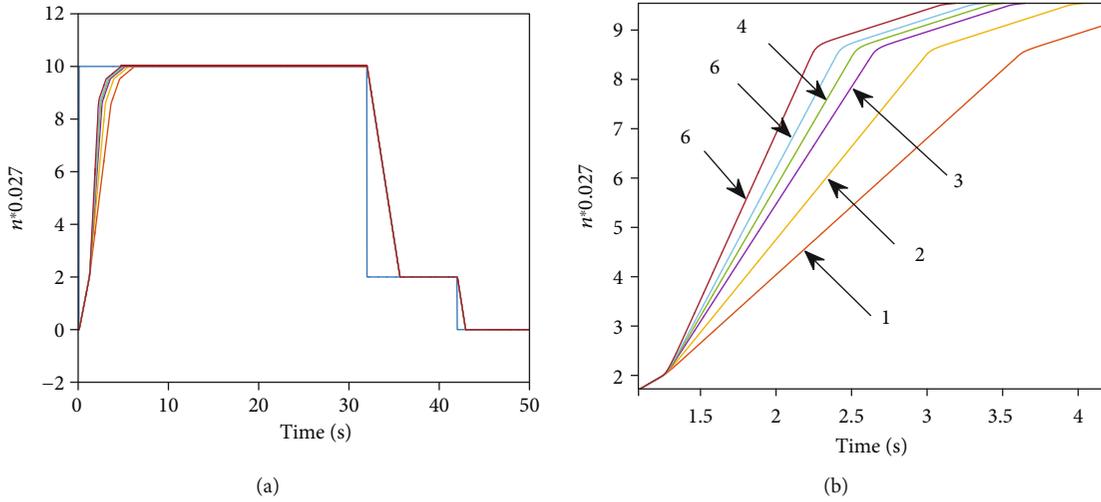


FIGURE 8: Output curve with expert PID.


 FIGURE 9: Output curves with variable parameters of expert PID. (a) Six output curves of the whole working process correspond to six different values of  $b_2$  shown in line 1 to line 6. (b) Corresponding starting processes.

absolute value of error is greater than  $a_i$ ,  $b_i$  is a constant value, and the control mode of the system is open loop control. When the error is smaller than  $M_1$ , the PID controller works, and several parameters are defined as follows: proportional parameter  $k_p$ , integral parameter  $k_i$ , differential parameter  $k_d$ , amplification gain coefficient  $k_1 > 1$ , Inhibition coefficient  $0 < k_2 < 1$ , at  $k$  and  $k-1$  times, error is  $e(k)$  and  $e(k-1)$ , controller output is  $u(k)$  and  $u(k-1)$ .

Expert control rules of mine hoisting system are designed as follows:

When  $|e(k)| \geq M_1$ ,  $n = 4$ , in order to get the desired starting process, the value of  $b_i$  ( $i = 1, 2, 3, 4$ ) is as  $b_1 < b_2, b_2 > b_3, b_3 > b_4$ , accurate values adjust according to the control needs.

If  $|e(k)| > a_1$ , then  $u(k) = b_1$ .

If  $|e(k)| > a_2$ , then  $u(k) = b_2$ .

If  $|e(k)| > a_3$ , then  $u(k) = b_3$ .

If  $|e(k)| > a_4$ , then  $u(k) = b_4$ .

When  $|e(k)| < M_1$ , PI control works; if the error is higher and its absolute value gradually increases, the regulator

TABLE 3: The value of the acceleration.

$b_2$	$Sl$	No. of curve
0.3	6.740	1 <sup>st</sup> in Figure 9
0.4	5.746	2 <sup>st</sup> in Figure 9
0.5	5.250	3 <sup>rd</sup> in Figure 9
0.55	4.753	4 <sup>th</sup> in Figure 9
0.6	3.760	5 <sup>th</sup> in Figure 9
0.7	2.767	6 <sup>th</sup> in Figure 9

should implement stronger control; if the error is lower and its absolute value increase, then implement general control to correct the tendency. If the absolute value decreases or the system are in the state of balance, the regulator implement according to conventional PID parameters.

If  $e(k)\Delta e(k) > 0$  and  $|e(k)| \geq M_2$ , then  $u(k) = u(k-1) + k_1 k_p e(k)$ .

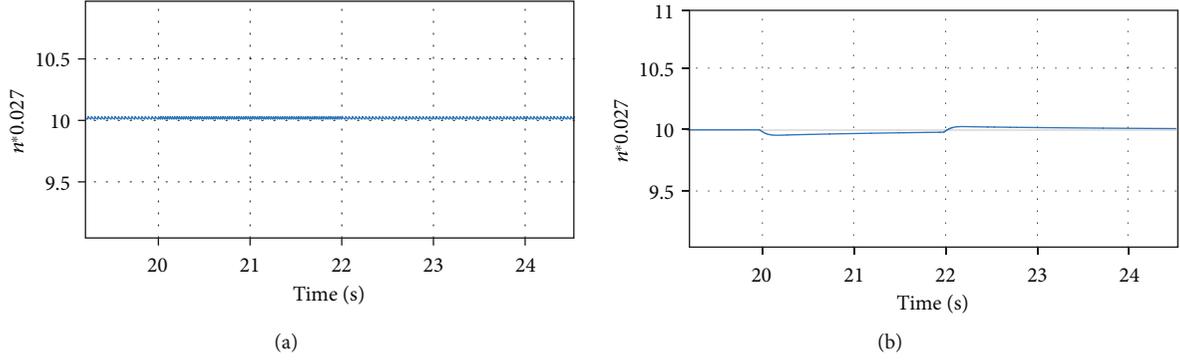


FIGURE 10: Impact of sudden load increase.

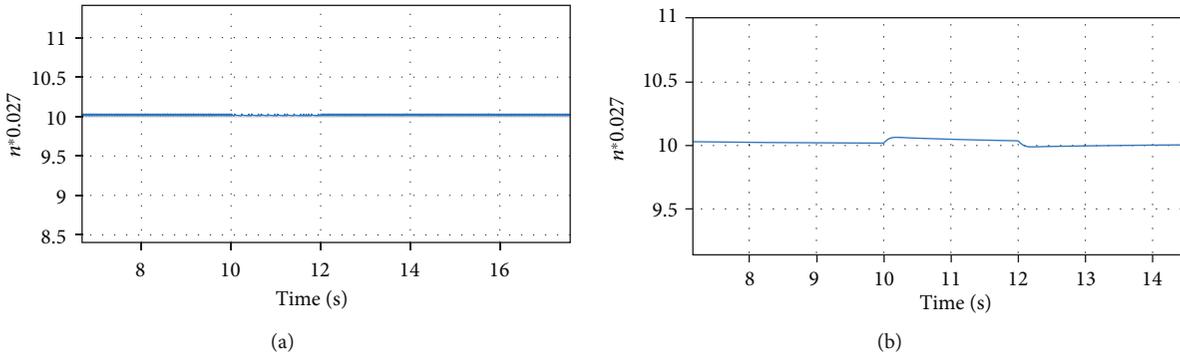


FIGURE 11: Impact of sudden load drop.

If  $e(k)\Delta e(k) > 0$  and  $|e(k)| < M_2$ , then  $u(k) = u(k-1) + k_2 k_p e(k)$ .

If  $e(k)\Delta e(k) < 0$  and  $\Delta e(k)\Delta e(k-1) < 0$  or  $|e(k)| = 0$ , then  $u(k) = u(k-1)$ .

If  $e(k)\Delta e(k) < 0$  and  $\Delta e(k)\Delta e(k-1) < 0$  and  $|e(k)| \geq M_2$ , then  $u(k) = u(k-1) + k_1 k_p e(k)$ .

If  $e(k)\Delta e(k) < 0$  and  $\Delta e(k)\Delta e(k-1) < 0$  and  $|e(k)| < M_2$ , then  $u(k) = u(k-1) + k_2 k_p e(k)$ .

If the absolute value of error is small enough, in order to decrease final error, conventional PI control is needed.

If  $|e(k)| \leq \varepsilon$ , then  $u(k) = k_p e(k) + k_i(e(k) + e(k-1)t_s)$ .

#### 4. Simulation Analysis

The simulation model is established based on a speed regulation circuit of the SCR-D system. The basic parameters are shown in Table 1.

**4.1. Control by the Conventional PID Algorithm.** From the given parameters mentioned above, we can get the error range is  $(0, 10)$ , and output range of controller is  $(0, 1)$ . Now, two kinds of control methods are used to the motor control system, one is an ordinary PID controller and another is an expert PID controller, and their control effects will be compared.

The given input signal curve and the corresponding output response curve of the system when the PI controller is used is shown in Figures 6 and 7, (a) is the output curve of the whole working process and (b) describes starting process.

In order to show the control effect, we unify the input and output signals into the same dimension. There are four output curves of the system both in Figures 6 and 7.

From the result get from Figures 6 and 7, we can find the acceleration in the starting process is large and overweight and weightlessness can be greater and the strain on the cable will be large. Although we can reduce acceleration and overshoot by reducing  $k_p$  or  $k_i$ , this will increase the error.

The respond parameter to different controller parameters is listed in Table 2.

**4.2. Control by the Expert PID Algorithm.** When expert PID algorithm is adopted, according to the expert rules, parameters are selected as follows:

$$\begin{aligned} a_1 &= 8.0, a_2 = 1.5, a_3 = 0.5, a_4 = 0.01; \\ b_1 &= 0.2, b_2 = 0.55, b_3 = 0.12, b_4 = 0.05; \\ k_1 &= 2, k_2 = 0.4; \\ k_p &= 60, k_i = 11.5, k_d = 0.01. \end{aligned} \quad (1)$$

When a given signal is descending for deceleration, the parameters  $a$  and  $b$  are turned into negative values of the response. The system response curve and the given input curve are shown as Figure 8.

Apparently, the curve in Figure 8 close to the ideal hoist process shown in Figure 1, that is, expert control is suitable for mine hoist control system.

If we want to change the acceleration of the startup process, we can change  $b_2$ , it plays a major role in the starting process. Increasing  $b_2$  can increase the starting acceleration, it can be shown by Figure 9.

The relationship between the performance index in the system startup process in Figure 9 and the value of  $b_2$  is shown in Table 3.

In Table 3,  $sl$  represent the slope of the of output curve when the output of expert controller is  $b_2$ .

In the designing of the expert controller of the mine hoist control system, the value of  $b_2$  is determined by the object to be transported. For example, for the system of transporting people, comfort is more important, the value of  $b_2$  should be smaller, and for system of transporting cargo, speed is more important, the value of  $b_2$  should be larger.

**4.3. Effect of Load Mutation.** Since the hoist is generally hoisted by a steel wire rope, which has certain elasticity, and load fluctuation may occur during operation, so this study adds the interference of load mutation.

In the period of constant speed operation (10 s, 12 s) and (20 s, 22 s), when the torque is increased by 30 or dropped by 30, the system will fluctuate slightly. The results are shown in Figures 10 and 11.

It can be seen from the figures that whether the load suddenly increases or decreases, both of these methods can effectively inhibit the effect of load mutation. Both of these methods can inhibit the effect of load mutation. However, the output curve of the system with expert PID algorithm fluctuates less (as shown in Figures 10 and 11(a)), while the curve of the system with PID algorithm fluctuates more (as shown in Figures 10 and 11(b)).

## 5. Conclusions

This paper is concerned with the research on the application of expert control on the DC speed control system, and the mine hoist control system which uses a DC motor is taken as the control object. By comparing the control result of conventional PID control the expert control, we can find that expert control is more suitable for the hoist control system. Firstly, the hoisting and stopping acceleration of the hoist system by expert control is less than the system which is controlled by conventional PI controller, and this will greatly improve comfort level of the people; this will also improve the safety of the system for smaller acceleration can reduce the strain on the cable. Secondly, the expert control mine hoist control system can be designed as having no overshoot, although conventional PID control can also make the system having no overshoot, but on this situation, the acceleration will be much larger and the system may be not safe. When designing an expert controller for a mine hoist control system, both the comfort and the safety should be considered, which are determined by the sense of overweight and weightlessness and the strain of the cable separately, and these are all determined by the acceleration during the starting and stopping period, the rules of expert controller and the control parameters are all determined by the facts mentioned above. It is need to be said that the expert rules in this paper is not

necessarily suitable other motor control system, especially the system that need positive and negative rotation and need changing frequently. Of course, this method could be extended to other applications, such as the elevators, the hoisting machines.

## Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

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