Application of Intellectual Control Treatment for Cement Grinding Process

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***Abstract*—This paper introduces a control scheme for the load in the grinding process of the cement raw mill against its characters of nonlinearity and large time delay. An expert control decision is proposed for the control of the grinding process of the cement raw mill. According to the relationship curves between mill load and the three parameters including mill sound, the back powder of the separator, the power load of the bucket elevator, and the expert knowledge bases which are got through further studying the concrete implementation method and technology for the transformation and expression from hidden knowledge to explicit knowledge, we established expert parameter setting incomplete differential PID controller to self-adapt to the operation conditions of three stages: "empty mill", "normal" and "blocked mill". The control system is with strong practicability, strong ability of anti-interference and good robustness, and its efficiency is improved greatly. Through further study of cement grinding process sampling period, expert variable cycle PID control strategy is put forward, and results show that response time is faster and the efficiency is further improved. The intelligent expert control system effective practice and simulation results are confirmed.**

Keywords- cement grinding process; expert knowledge base; expert parameter setting PID; expert variable cycle setting PID; the fusion of intelligent

I. INTRODUCTION

Cement grinding process play an important role in cement industrial production, which affects the quality and various performance indicators of the cement directly [1].Using automatic control for cement raw mill load can avoid appearing "empty mill" and "blocked mill" phenomenon, as well as save large amount of electricity. However, the grinding of the cement raw meal is too complex to establish mathematical model ,which is nonlinear, big lag and difficult. Using some advanced or routine algorithm such as PID control algorithm can control the filling quantity of mill material at optimum performance for a time. But this algorithm are easy to occur the disorder control with heavy interference, then "empty mill" and "blocked mill" phenomenon will appear; Once appearing this phenomenon, will reduce the efficiency and hold up production.

The development of artificial intelligence technology provides the corresponding theoretical basis for the control of cement mill load[2]. Expert control is an intelligent controller which is developed from the combine of the expert system technology based on the artificial intelligence and control theory. The substance of expert control is a controller designed through the intelligent ways by using the knowledge based on the controlled objects and control rules[3]. Intelligent expert control system is a hotspot in the field of control theory in recent years which has extensive application prospect.

II. TYPE GRINDING PRODUCTION PROCESS AND RUNNING CHARACTERISTIC

The process of cement grinding production is as follows: the conveyor belt send the materials into the ball mill to grind, then the materials are unloaded through the mill tail after ground by mill, then delivered to the separator through the bucket elevator. The materials are divided into fine grinding material flow and coarse grinding material flow after classification. The fine grinding material flow directly output as a finished product, the coarse grinding material flow returns to the feed inlet of the mill for grinding again. The grinding condition can be divided into three stages:"Empty mill"；"Normal"；"Blocked mill".

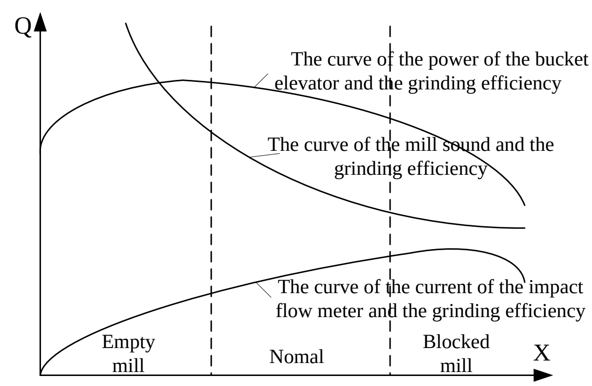

Figure 1. The curve graph of the production parameters in grinding process and the production efficiency

Many factors affect the cement grinding process, this three parameters including can reflect the motion characteristics effectively, they are mill sound, the back powder of the separator, the power load of the bucket elevator: electric ear measure mill sound (F(k)). impact flow

The research and application demonstration of cement grinding optimization control system facing saving energy and reducing consumption, the project number: 2012GGB01138 .

meter the back powder of the separator (I(k)). measuring the motor power measure the power load of the bucket elevator (P(k)).

As shown in the figure 1, we can see that the control process of the mill load can be divided into three stages: "Empty mill"; "Normal"; "Blocked mill"[4].

III. EXPERT CONTROL RULES

The core of expert control is the construction of knowledge base[5], further explore the concrete implementation method and technology for the transformation and expression from hidden knowledge to explicit knowledge, we obtain the expert knowledge base of the grinding process. Control algorithm is simple, it has well robust and has used in many cement plants. According to the curve graph of the production parameters in grinding process and the production efficiency, we divide each phase into three rules, there are totally nine rules. The data in table 1 can be made a few minor adjustments for different types of mill[4].

TABLE I. THE RULE TABLE OF THE EXPERT KNOWLEDGE BASE

Pheomenn	SP	BP	LE	The new Additiveamount	waiting time	rule
Empty mill	SP > uv	BP>u		Increase a certain value	τ_1	1
		nomal			τ_2	2
		BP<l			τ_3	3
Nomal nomal	SP > uv	BP>u		Slowly	τ_4	4
		nomal		keeping	τ_5	5
		BP<l		Slowly	τ_6	6
Stifled mill	SP< l v		LE>uv	reduce a certain value	τ_7	7
			nomal		τ_8	8
			LE<lv		τ_9	9

In table 1, SP: sound pressure, BP: the back powder, LE: the load of bucket elevator, uv: upper limit value, lv: lower limit value.

This algorithm has been used in industry production，Practices show that the this expert control improved the stability of the mill load greatly, and improve the production efficiency, increase the efficiency up to about 75%, In order to further improve the production efficiency, on the basic of expert intelligent control system, Propose expert parameter setting incomplete differential PID control algorithm.

IV. EXPERT INCOMPLETE DIFFERENTIAL PID CONTROL

Expert control rules are essentially increased and decrease slowly to concrete, which reach the final process of optimal load state; expert intelligence control system Mentioned in ref. [4] is formulation and intelligent for rules, which can form intelligent expert control system furthered generalizations. Cement grinding process is a big lag link, so the system can use not fully differential PID control algorithm. The algorithm can greatly improve mill achieve optimal load rate, and avoid cause the overflow of shortcoming of computer data because Ideal type PID control algorithm amplitude modulation value is too large[6].

But in the actual engineering practice, with the change of the system state, a state set the optimal PID parameters may not apply to another state, which are difficult to achieve the best control effect, Incomplete differential expert parameter setting PID control is combined the expert system with incomplete differential PID controller, and to automatically adjust the incomplete differential PID parameters through expert rules, which achieve the best control effect[7]and have a good control characteristics and robustness, so the system is widely applied in industry[8].

According to the size of the current deviation and its change rate, incomplete differential expert parameter setting PID control rule revise the new proportional coefficient Kp,integral coefficient Ki,differential coefficient Kd, the expert PID control system structure as shown in figure 2:

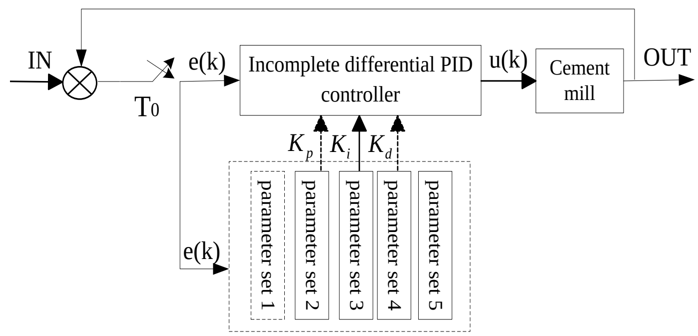

Figure 2. The expert parameter setting incomplete differential PID control system structure

K_p express proportion coefficient of controller, K_i express integral coefficient, K_d express derivative coefficient. e(k)、e(k-1)express the error value of the present and the previous sampling time,T_0 is 5min generally, u(k) express the Kth output value , OUT (k) express output value, IN express given value.

Incomplete differential PID control algorithm[9]:

$$u(k) = u(k-1) + \Delta u(k)$$

u(k-1) express the (K-1)th output value, Δu(k) express the Kth output increment value , the incremental form governing equations of the incomplete differential PID:

$$\Delta u(k) = K_p[e(k) - e(k-1)] + K_i e(k) + K_d(1-\alpha)\begin{bmatrix} e(k) - 2e(k-1) \\ + e(k-2) \end{bmatrix} + \alpha\, \Delta u(k-1)$$

Note: $\alpha = T_f/(T_f+T_0)$, T_0 express sampling period, T_f express filter coefficients.

Expert incomplete differential PID controller is based on the incomplete differential PID, Gradually change Kp、Ki and Kd，Based on the operational features of the mill,this parameter set are given according to the mill running condition and change trend of the error, five groups are as follows:

parameter set 1: $Kp=k_1*k_p$，Ki =0，Kd =0;

parameter set 2: $Kp=k_1*k_p$，$Ki = k_1*k_i$，$Kd = k_1*k_d$;

parameter set 3: $Kp=k_p$, $Ki = k_i$, $Kd = k_d$;

parameter set 4: $Kp=0_p$, $Ki =0$, $Kd =0$;

parameter set 5: $Kp=k_2*k_p$, $Ki =0$, $Kd =0$。

k1 express gain coefficient, k1>1; k2 express inhibitive coefficient. 0<k2<1;

The states of mill that five parameter sets apply to are as follows:

(1) In "empty mill" stage ($F_k>F_{max}$) and "blocked mill" stage ($F_k<F_{min}$), should make the actual load value approximate the given value quickly, increase the proportional action as far as possible and cancel the role of the integral[10]. F_s, F_{min}, F_{max} stand for the set value, the minimum value, the maximum value of SP.

(2) In "empty mill" stage ($F_k=F_s$) ,the mill load is near optimal.

1) when $e(k)*\Delta e(k)>0$ or $\Delta e(k)=0$,shows that the error move in the direction of increase error absolute value, or the error is a constant who did not change.

If $|e(k)|>M_2$, shows that the error is bigger, at this time we can consider to increase the proportional control, in order to quickly reduce the absolute value of the error and fast to reach best load of the mill, we adopt the parameters in group 2.

If $|e(k)|<M_2$, shows that the error move in the direction of increase error absolute value, but the itself of the absolute value of the absolute value of the error itself is not very big, we can consider to implement the general control function by using parameter set 3.

2) When the $e(k)\cdot\Delta e(k)<0$, $\Delta e(k)\cdot\Delta e(k-1)>0$ or $\Delta e(k)\le\varepsilon$ (precision), shows that the error move in the direction of decrease error absolute value, or has reached equilibrium state, using the parameter set of 4.

3) When $e(k)\cdot\Delta e(k)<0$, $\Delta e(k)\cdot\Delta e(k-1)<0$, shows that the error is in the extreme sate. If the absolute value of the error is bigger, mean $|e(k)|\ge M_2$, we can consider implementing the stronger control function by using the parameter set 1.

If the absolute value of the error is smaller, mean $|e(k)|<M_2$,, we can consider implementing the weaker control function by using the parameter set 5.

The above rules, e(k-2) express the error value of the first two sampling time, $\Delta e(k)=e(k)-e(k-1)$; M_1、M_2 is the experience value, and $M_1> M_2$; ε is arbitrarily small positive number.

V. INCOMPLETE DIFFERENTIAL EXPERT VARIABLE CYCLE PID CONTROL

When the mill in the normal stage, the material filling rate is bigger, the mill efficiency is highest and the mill in the best state [1]. Because of the deviation is small in this stage, we put forward the expert variable cycle PID control in order to avoid the unnecessary volatility of the mill load caused by frequent sampling. The sampling period T_0 will be given according to the error. The basic difference between the variable cycle sampling and fixed cycle sampling is that the sampling period of the former is changed with the error which has an adaptive characteristics. System structure diagram is shown in figure 3:

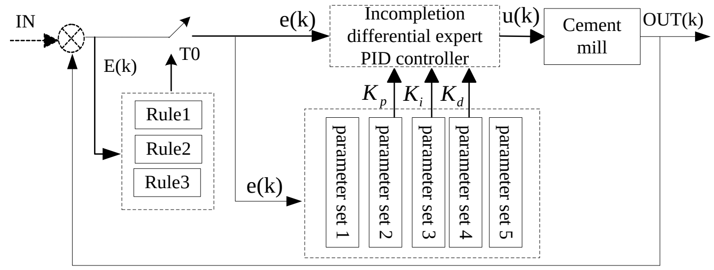

Figure 3. The expert period sampling incomplete differential PID control system structure

$E(k)$ is continuous signal, the rules of the sampling period when the mill worked in the normal stage is as follows:

Rule 1: when $E(k)>A$, $T_0=2\min$.

Rule 2: when $B<E(k)<A$, $T_0=5\min$.

Rule 3: when $E(k)<B$, $T_0=10\min$.

A, B is the deviation threshold of the system.

The simulation and practice result anti-interference ability and robustness of the system s show that the expert variable cycle PID controller further improved the anti-interference ability and robustness of the system and improve the mill running efficiency.

VI. THE SIMULATION AND RESULTS

We approximate the control system of the incompletion differential expert PID controller as second-order inertia system with a delay, the control model as follows:

$$G(s)=\frac{1}{400s^2+60s+1}\exp(-20s)$$

The cement mill control system has time-varying characteristics. The transfer function just represents the characteristics of the mill in a stable condition which can't represent the whole condition. The purpose of the modeling is for the simulation experiments, in order to understand the operation features of the mill much better.

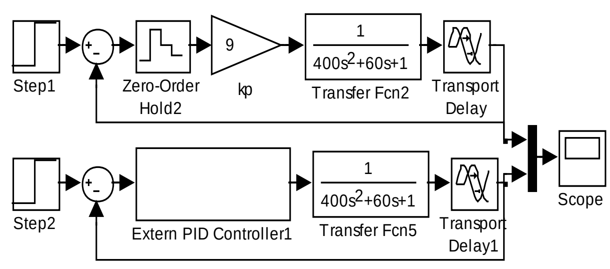

Figure 4. The system simulation model

According to the expert control system and the incomplete differential expert parameter adaptive PID control system introduced in this paper, we take simulation by using Simulink toolbox of the Matlab software when the mill work in the "normal" stage. The simulation results are shown in figure 4.

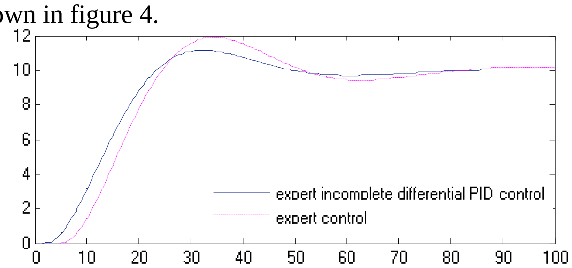

Figure 5. The Matlab simulation diagram

The curve 1 in the figure 5 is the to control the response curve of the expert system, this stage can be approximately as proportional control, according to expert experience $K_p=7,T_0=5$;

The curve 2 is the response curve of the incomplete differential expert PID control, according to the experience of the experts, the initial value adopt $K_p=5,K_i=0.000375$, $K_d=20$, $T_f=80$, M1=0.1, M2=0.018, $K_1=5$, $K_2=0.4$, $T_0=5$, $\varepsilon=0.005$.

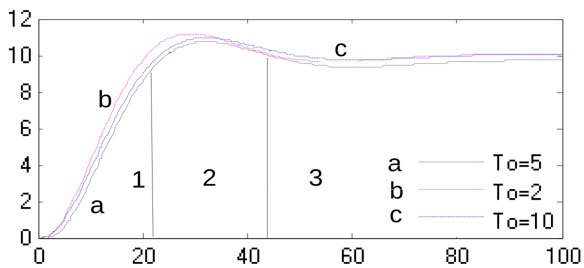

Figure 6. expert variable cycle PID simulation curves

The Figure 6 is the simulation curves of the incomplete differential expert PID control system when the sampling period T_0 respectively adopts 2, 5, and 10.

Rise time t_r:b<c<a;

Overshootσ :a<c<b;

Accommodation time t_s:a<b<c;

The error is bigger when in 1 area, because of the curve b rising fastest, when $T_0=2$ the mill work best; The error decreases in the 2 area, the overshoot of the curve α is minimum, when $T_0=5$ the mill work best; The error is minimum in 3 area, the curve 3 first reach the steady state, when $T_0=10$ the mill work best.

The above analysis shows that in the adjustment process of grinding machine, we can further improve the run efficiency of mill through the implementation cycle variation sampling according to the situation changes of the error.

VII. CONCLUSION

The control effect of the incomplete differential expert parameter self-adaptive PID control system and the expert variable cycle PID control for the cement grinding process is much better than the expert control system and the efficiency can reach almost 90% which have proved by simulation and practice. This control system has certain reference value for general industrial powder system and blast furnace feeding system. Once established the control rules in accordance with the actual need and adopt the algorithm in this paper, we can make the control system to achieve optimal control. Certainly the intelligent expert control system need to be constantly improving, we need to further research the intelligent expert control system with higher efficiency combined with the actual.

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