Control Method of the Weight of Steady Flow Silo based on Expert Control and Bang-Bang Control

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Abstract. Through the combination of expert control and bang-bang control, the circulating fan in cement grinding process equipment is controlled to affect the silo weight of steady flow silo, to realize the stability of silo weight and to improve the production efficiency. Firstly, the correlation between the stability of silo weight and the improvement of production efficiency is introduced, and several conditions affecting the silo weight of steady flow are summarized. Then the control principle and the control algorithm are introduced emphatically. Finally it is proved that the method can stabilize the weight of the steady flow silo by controlling the speed of the circulating fan with matlab to draw the field data into a graph.

1. Introduction

Cement industry is the main pillar industry of our national economy. Cement is used not only in industrial and civil construction, but also in transportation, urban construction, agriculture forestry, water conservancy, military, seaport and other new industrial construction projects. And it is the national construction and indispensable important material [1] in people's life. Cement grinding is the end link of cement production, including cement pre-grinding and cement final grinding stage. The improvement of production efficiency in cement pre-grinding stage can reduce the pressure in the subsequent final grinding stage, in order to improve the production efficiency of the whole process of cement grinding.

At present, many scholars devote themselves to improving the efficiency of cement grinding. For example, reference [2] is to improve the efficiency of cement grinding by adding grinding aids. In addition, reference [3] provides a method to improve the efficiency of cement grinding by using high-efficiency separator. External force intervention or modification of site equipment is needed in the above methods of improving the efficiency of cement grinding.

This paper starts with the control method and improves the production efficiency by controlling the relevant equipment to ensure the stability of the steady flow silo weight, thus improving the production efficiency. In the classical control, before the industrial equipment is controlled, the mathematical model should be established according to the operation of the field equipment, and the corresponding control of the field equipment should be carried out through the model. Due to the long-lag and nonlinear process as well as the difficulties in modeling, this paper adopts a method from the view of control which combines the expert control and the bang-bang control in order to improve the efficiency of cement production.

Expert control belongs to the category of intelligent algorithm. In the absence of an accurate model of the system, this method controls the system according to the knowledge base established from the expert experience and the corresponding reasoning machine. As described in reference [4], expert control was successfully used in cement grate cooler system.

Bang-Bang control is a common control form in the field of engineering. Its mechanism is to take the control variables as the positive maximum or negative maximum within the allowable control range in the whole process. As described in reference [5], Bang-Bang control has been successfully used in vertical roller grinding control.

2. Qualitative relationship between steady flow filo weight and cement grinding efficiency

The stability of the weight of steady flow silo is very important for the whole cement clinker grinding process[6].In the actual production process, if the steady flow silo weight is stable, stable material column can be produced at the bottom of the silo. The material column enters rolling machine steadily and incessantly through the bottom of steady flow silo. In this state, the roller pressure efficiency of rolling machine goes into a higher level, and the incoming materials are pressed finer, which is conducive to the the follow-up power selection and grinding.
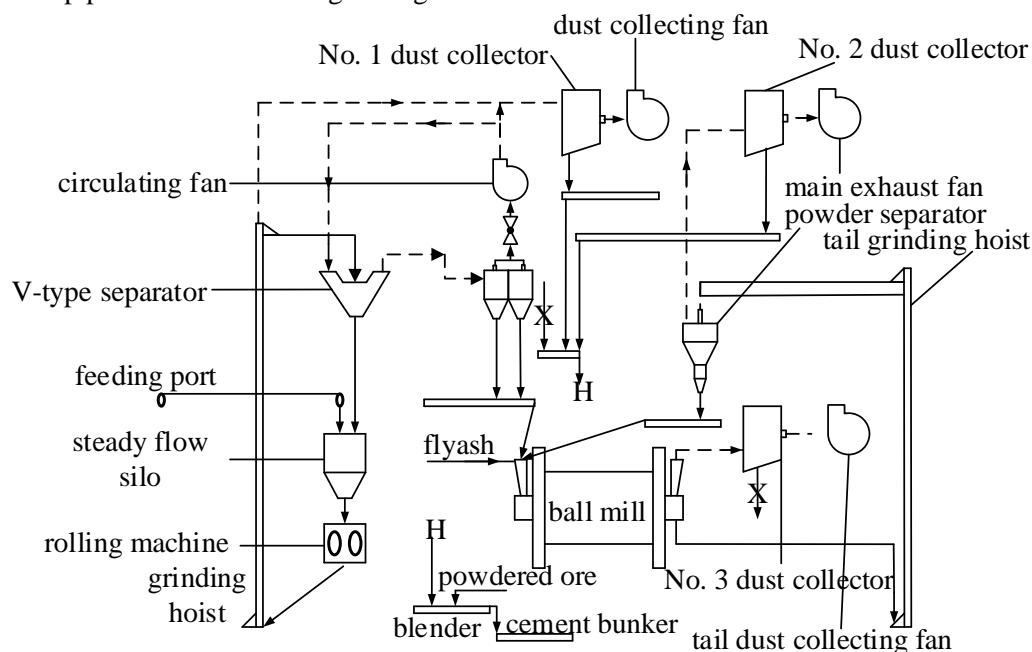
Figure 1. Flow cart of cement combined grinding process

Figure 1 shows the process of cement combined grinding. The materials are fed into the feeding port and sent to the steady flow silo through the conveyor belt. The material column enters rolling machine steadily and incessantly through the bottom of steady flow silo. The cake extruded by the roller wheel of the rolling machine is fed into the V-type separator by the grinding hoist. After the separation of the V-type separator, some fine particles are collected by the No. 1 dust collecting fan into the blender and the other is mixed with flyash into the ball mill. Under the grinding action of ball mill, fine dust produced during grinding is collected by No. 3 dust collector and enters into the blender. The rest of the grinding materials in the ball mill are continuously fed into the powder separator through the tail grinding hoist. Under the influence of the separator, fine particles enter into the blender and the coarse particles re-enter into the ball mill for grinding [7].

As is shown in table 1, when the weight of the steady flow silo is stabilized, the roll pressing efficiency of the rolling machine reaches a higher level. So in the first stage, the material entering the No. 1 dust collector increases, which reduces the burden of the ball mill and makes the whole grinding process more efficient.

Table 1. Qualitative relationship between steady flow filo weight and cement grinding efficiency

weight of steady flow silo	efficiency of rolling machine	burden of ball mill	Grinding efficiency
unstable	lower	higher	lower
stable	higher	lower	higher

3. Control thought

Cement grinding process is a typically nonlinear, large lag link, which requires a high control level, and the general control method is very difficult to meet the control requirements. In this paper, a method of expert control [8] combined with bang-bang control [9,10] is adopted. As is shown in figure 2, as for general working conditions, expert control is used to stabilize the steady flow silo weight in the case of slight fluctuation, while bang-bang control is used for unusual working conditions, which makes the response time of the system short and restores the weight to its desired state quickly.
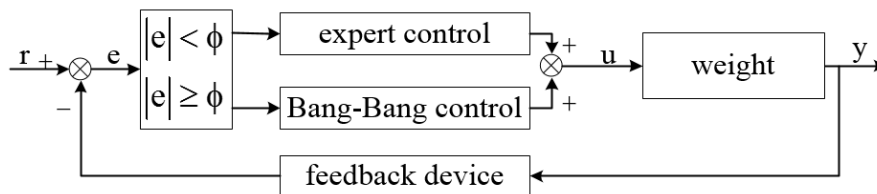
Figure 2. Control scheme structure diagram

Expert control generally consists of knowledge base, inference engine and other parts [11]. Based on the operating experience of the excellent operators and combined with the production techniques of the specific plants, the software summarizes an expert-control knowledge base that fits the plant. According to the data stored in the database as well as the DCS [12] and the expert control knowledge base, the reasoning machine makes corresponding judgement.

The idea of Bang-bang control is to divide the deviation between the ideal silo weight (n) and the actual silo weight (w) into three control ranges as shown in (1).

$$n - w \begin{cases} \in (-\infty, -\phi] \\ \in (-\phi, \phi) \\ \in [\phi, +\infty) \end{cases}, \tag{1}$$

When the deviation between the ideal weight and the actual weight is within the allowable range $(-\phi, \phi)$, the Bang-Bang control method does not act on the field equipment. When the deviation is off the threshold ϕ, the Bang-Bang control begins to work, which makes the field equipment move greatly and draws the deviation within a reasonable range quickly. This paper controls the weight according to the three ranges in (1). When the deviation satisfies $(-\infty, -\phi]$ and $[\phi, +\infty)$, the corresponding equipment is operated by a large margin, and when the range $(-\phi, \phi)$ is satisfied, the expert control is carried out.

4. Advantages of combining Bang-Bang control with expert control

The combination of Bang-Bang control and expert control can give play to their respective advantages. Expert control is suitable for accurate control of small deviation. In the case of small deviation between target weight and actual weight, expert control can make corresponding judgment according to the situation on the spot, which belongs to the category of fine adjustment. The single use of expert control results in deviations when the bias accumulates too much, which requires Bang-Bang control to intervene. The Bang-Bang control is suitable for situations where the deviation is too large. The deviation accumulates in the long-running process of the system and it is likely that there is a large deviation between the actual silo weight in the field and the ideal silo weight required by the program. Once the deviation accumulation exceeds the allowable range of Bang-Bang control, the software carries on the big action to the field equipment, reducing the deviation quickly.

In addition, Bang-Bang control has its advantage in dealing with field emergencies. For example, sudden breaking materials on the spot, that is, no new raw materials enter the feeding port for some reason. Under such circumstances, the weight of the steady flow silo will drop sharply. What's even

worse, once the empty silo appears and the raw materials enter again from the feeding port, it will have a great impact on the steady flow silo and damage the equipment. Besides, once the program detects that the silo weight is too small and enters the Bang-Bang control area, the program will greatly reduce the rotating speed of the circulating fan and the speed of the drop in the silo weight in order to avoid excessive fluctuations in the weight of the silo. At the same time, it buys time for the field staff to deal with the unexpected situation.

5. Summary of methods for controlling weight stability of steady flow silo
Figure 1 shows the three conditions related to the weight of the steady flow silo: rotating speed of circulating fan (SOCF), feeding quantity (FQ) and opening degree of rolling machine oblique board (ODOB). In addition, the dry or wet condition of the material (COM), current of movable and fixed rollers for rolling machine (CORM) are also related to the steady flow silo through the field observation. This paper combines these conditions together and presents them in table 2.

Table 2. Conditions related to storehouse weight

condition	action	weight
SOCF	increase	reduce
	reduce	increase
FQ	increase	increase
	reduce	reduce
ODOB	increase	reduce
	reduce	increase
COM	dry	reduce
	wet	increase
CORM	increase	reduce
	reduce	increase

According to the actual situation of the industrial site , FQ , ODOB , COM and CORM are not mentioned in this paper . This paper only mentions the method of controlling the speed of the circulating fan to make the weight of steady flow silo smooth.

6. Software structure
Figure 3 shows the software structure. The program includes database operation subroutine, circulating fan control program and OPC[13] Client subroutine. According to the industrial situation, the data interaction between the circulating fan control program and the field DCS is realized by OPC Client subroutine. At the same time, the collected DCS data and the written data in the DCS are stored in the database by the database operation subroutine.
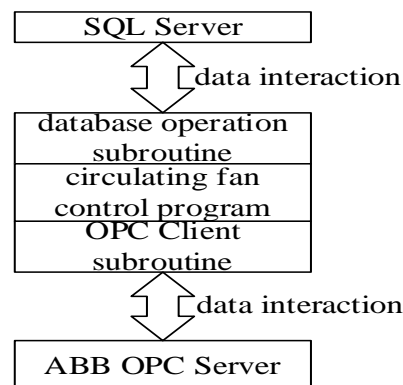
Figure 3. Software structure

7. Programming

According to the expert experience, the ideal state of steady flow silo weight is to control the silo weight to a fixed weight n, so the ideal state of the program is to stabilize the silo weight to this weight. In the practical operation, it should set the ideal value as the midpoint and Set up upper limit n_3 and lower limit n_2 of the silo weight as well as the maximum limit n_4 and minimum limit n_1. (2) to (6) show their relationship.

$$n_1 < n_2 < n_3 < n_4 , \tag{2}$$

$$n_2 = n - \varphi , \tag{3}$$

$$n_3 = n + \varphi , \tag{4}$$

$$n_1 = n - \phi , \tag{5}$$

$$n_4 = n - \phi , \tag{6}$$

The program reads real-time data from the field DCS at a rate of one per second. The data is filled into the array with length 500 in turn, and the data in the array is processed to obtain the dynamic quantization value of the weight increase or subtraction. Starting with the latest data, $M \times N$ pieces of data are intercepted, and the data is truncated into M parts, containing N pieces of data individually. The N parts are processed as follows:

$$\overline{X}_m = \sum_{i=500-n+1}^{500-(m-1)n} \frac{x_i}{n} \quad \left(m = 1,2,3,4; n = 20 \right) . \tag{7}$$

Four mean values are obtained from (7), they are $\overline{X}_1, \overline{X}_2, \overline{X}_3$ and $\overline{X}_4$. If it decreases from $\overline{X}_1$ to $\overline{X}_4$ in turn, it means that the steady flow silo weight is decreasing, and vice versa. That is to say, the (8) shows that the steady flow silo weight is decreasing. the (9) shows that the steady flow silo weight is rising.

$$\overline{X}_1 > \overline{X}_1 + \delta, \overline{X}_2 + \delta > \overline{X}_3, \overline{X}_3 + \delta > \overline{X}_4 , \tag{8}$$

$$\overline{X}_1 + \delta < \overline{X}_2, \overline{X}_2 + \delta < \overline{X}_3, \overline{X}_3 + \delta < \overline{X}_4 , \tag{9}$$

When the silo weight is satisfied $n_2 < w < n_3$, check if w is smaller than (10), if so, then the speed of circulating fan is reduced by (11). Perform the opposite action when w is greater than (10).

$$\frac{n_2 + n_3}{2} - \varepsilon , \tag{10}$$

$$step2 \times \frac{n_2 + n_3}{2} , \tag{11}$$

When the silo weight is satisfied $n_1 < w < n_2$, if a drop in silo weight can be detected, then the speed of circulating fan is reduced by (12). If an increase in silo weight can be detected, then the speed of circulating fan is increased by (13). If any trend in silo weight can be detected, the speed of the circulating fan does not move. Perform the opposite action when w matches $n_3 < w < n_4$.

$$(\overline{X}_1 - \overline{X}_4) \times step1, \tag{12}$$

$$(\overline{X}_1 - \overline{X}_4) \times step2, \tag{13}$$

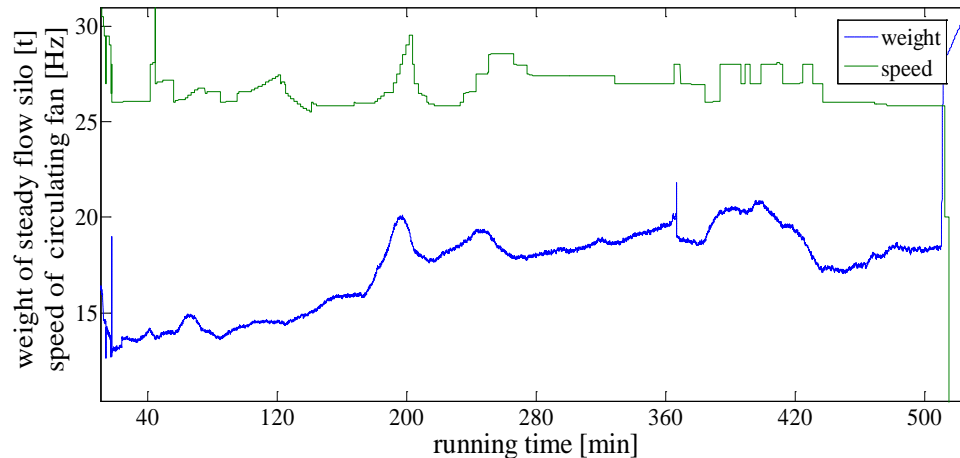The circulating fan is reduced when the weight of the silo is satisfied $w<n_1$. Perform the opposite action when the silo weight meets $w>n_4$.

8. Results of industrial field application

By communicating with technicians such as field operators, the parameters need to be set to values in table 3 before the program is applied.

Table 3. Setting parameter values

parameter	Value
n	22
φ	2
ϕ	1
δ	0.05
ε	0.5
Step1	2
Step2	1

Figure 4. Field application result a

Figure 4 runs for about 9 hours, software starts with mill start. The actual silo weight of steady flow silo is about 13 tons when the software is started. Field worker changes n to 13.5 and change φ to 0.5, so the lower limit of software silo weight is set to 13 tons and the upper 15 tons. The actual operation result is that the silo weight is stable within the limit, and the expected effect is achieved. About 3 hours ago, in order to test the program's ability to withstand pressure, field worker changes the lower limit of the software siol weight n_2 to 17, n_3 to 20. The silo position goes up immediately and stabilized within the setting range after a little overshoot. When the software runs in automatic state for about 9 hours, the weight is still within the range, showing a more and more stable trend, as the ball mill shuts down and exits the software.
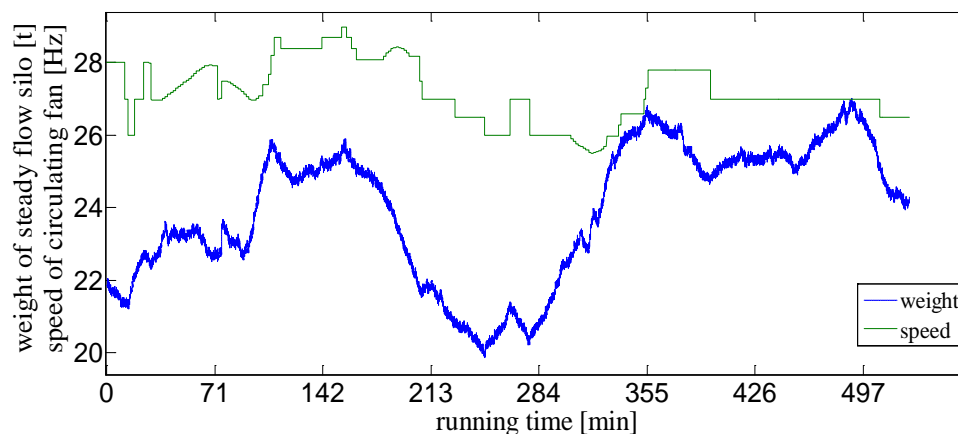
Figure 5. Field Application Result b

The running record in figure 5 shows the anti-jamming ability of the software. The formation of the troughs is due to the large reduction of accidental feed in the field. When the silo weight is stabilized to 25 tons or so, the silo weight presents a precipitous descent and the rotating speed of the circulating fan is reduced rapidly after the program detects. The weight is stabilized to the low position of 21 or so automatically. When the incoming materials are normal, the weight which controlled by the circulating fan will continue to be stable at about 25 tons.

9. Summary
As is shown in figure 4 and figure 5, the program can automatically judge the silo weight and the upward or downward trend. It can quickly control the circulating fan to an appropriate rotational speed by the light change of the silo weight, thus maintaining the stability of the silo weight and achieving the expected effect.

This paper also has some limits, as described in the table 2, there are five conditions that affect the weight of the steady flow silo, and only one of them is explored in this paper.

10. Acknowledgement

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