Intelligent Control System for Cement Raw Mill Quality Based on Online Analysis

Yu Hongliang
School of Electrical Engineering
University of Jinan
Jinan, China

Lian Guodong
School of Electrical Engineering
University of Jinan
Jinan, China

Wan Xin
School of Electrical Engineering,
University of Jinan,
Jinan, China

Wang Duo
Department of Electrical and Electronic Engineering
Imperial College London
London, United Kingdom

Wang Xiaohong
School of Electrical Engineering
University of Jinan
Jinan, China

Abstract—**Conventional proportioning control of cement raw mill is basing on off-line analysis results obtained once per hour. According to the given values of the indexes K, n and p (sometime Fe_2O_3 used instead of *p*), operators adjust proportions of raw materials with operating experiences. Due to the time lag in Analysis result and inaccuracy, the indexes of raw material fluctuates between control action intervals and the raw mill quality is low. To solve this problem, we present an intelligent control scheme for cement raw mill quality control based on online compositions analysis results. In this control system, the chemical composition in raw mill is measured in real-time and comprehensively analyzed. A condition-based intelligent control method is then used to optimally control the process. The application in one Cement Enterprise proves quality and efficiency of the system.**

Keywords—raw mill quality, composition online analysis, intelligent control.

I. INTRODUCTION

Cement industry is one of the pillar industries in China. The cement production is typical streamlined production process. The different raw materials are crushed, proportioned, milled, sintered and etc., to be made into cement. In the proportion sub-link, raw materials are mixed according to a certain ratio. In general, the mixing ratio of raw materials determines the quality of raw material and clinker. The paper presents an intelligent control system for raw material proportioning control and quality control based on online composition analysis[1][2][3].

Generally, in the process of proportioning there are three or four kinds of raw materials. To ensure the raw mill with suitable oxide composition, the different raw materials should be mixed in certain proportions. In other words, to ensure the raw mill quality, three indexes should be kept in a certain value stably.

The three indexes are calculated as following.

$$K = \frac{CaO - 1.65 Al_2O_3 - 0.35 Fe_2O_3}{2.8 SiO_2} , \quad (1)$$

$$n = \frac{SiO_2}{Al_2O_3 + Fe_2O_3} , \quad (2)$$

$$p = \frac{Al_2O_3}{Fe_2O_3} , \quad (3)$$

Therefore, the composition of raw materials should be measured in advance to ensure the raw mill quality.

At present, in most of cement enterprises in China, the measurement are mostly based on off-line analysis. And the general adjusting process of proportion is as the following. The laboratorian takes a sample manually in a certain time interval (generally one or two hours), and then the sample is analyzed in the laboratory. Afterward the result and the three indexes (K, n, p) are submitted to the operator. At last the operator adjusts the material flow through the DCS with experience manually. These off-line measurement has problems such as time lag and arbitrary operation. So in most cement enterprises the quality rate of raw mill is low[5].

Some cement enterprises have used online analyzer based on neutron activation analysis (PGNAA) technologies to realize real-time detection of raw mill composition, but there

International Journal of Advances in Computer Science & Its Applications– IJCSIA
Volume 5 : Issue 2   *[ISSN : 2250-3765]*

Publication Date: 30 October, 2015

are still some problems as arbitrary operation (manual mode) or bad adaptivity (automatic mode). Meanwhile, with the increasing importance of environmental concerns, both the cost and maintenance limit the application of this kind of technology [6][7].

For this reason, we designed an intelligent system based on near-infrared spectroscopy (NIR) technology to realize automatic proportioning and raw mill quality control.

II. FRAME OF INTELLIGENT CONTROL SYSTEM FOR CEMENT RAW MILL QUALITY BASED ON ONLINE ANALYSIS

The system contains an online analyzer of the chemical composition of raw mill which based on NIR technology (SpectraFlow). The analyzer is located on air-slide and provides real-time (the frequency of testing and sampling can be once per minute) NIR spectroscopy of raw mill after mill. The analyzer sends spectroscopic data to the analysis computer for calculation and analysis, and then the chemical composition data which were obtained are sent to a control computer for ratio control calculation. Finally, the set values of raw materials proportion are sent to DCS which adjusts the speed of each raw material belt automatically. The system diagram is showed in Fig. 1.

Fig. 1. System diagram

III. THE METHOD OF INTELLIGENT PROPORTION AND RAW MATERIAL QUALITY CONTROL

Using the initial values of raw material proportioning and the values of raw material chemical composition from current DCS, according to (1) - (3) and (4), the control computer calculates the theory values of chemical composition and the indexes of raw mill.

$$\begin{cases} C = a_{11}n_1 + a_{12}n_2 + a_{13}n_3 + a_{14}n_4 \\ S = a_{21}n_1 + a_{22}n_2 + a_{23}n_3 + a_{24}n_4 \\ A = a_{31}n_1 + a_{32}n_2 + a_{33}n_3 + a_{34}n_4 \\ F = a_{41}n_1 + a_{42}n_2 + a_{43}n_3 + a_{44}n_4 \end{cases} \quad (4)$$

In (4), $a_{11} \sim a_{14}$, $a_{21} \sim a_{24}$, $a_{31} \sim a_{34}$ and $a_{41} \sim a_{44}$ represent the content of chemical composition of raw materials. C, S, A, and F represent the content of CaO, SiO_2, Al_2O_3 and Fe_2O_3 of raw mill, and $n_1 \sim n_4$ represent the

ratio of raw materials. They are all percentage values. The $n_1 \sim n_4$ values sum to 1.

The composition of raw materials are tested offline, which causes deviations between theoretical values and real values of indexes, an algorithm of rolling multivariate regression is needed to realize mapping between them. Then we calculate the deviations between the set points and theoretical values of the indexes after mapping. Combining with the cement process theory and the operators' experiences, we judge the current condition intelligently and give an actual control rule. At last, with these rules of TABLE I, the constraint of the limits and the step, we search the optimal ratio by global incremental aiming at the minimum sum of square of the deviations (as (5)).

$$E = (1.2 \times (K - K_1) \times 5)^2 + (n - n_1)^2 + (p - p_1)^2 \quad (5)$$

In (5), E is the sum of square of the deviations, K, n, p are the real values of the indexes, K_1, n_1, p_1 are the set points of the indexes.

Operating conditions and corresponding control rules are shown in TABLE I.

CN	K	n	p	C	S	A	F
1	H	H	H	D			I
2	H	H	M	D		I	D
3	H	H	L	D		I	
4	H	M	H	D	I		I
5	H	M	M	D	I	I	I
6	H	M	L	D	I		D
7	H	L	H	D	I	D	I
8	H	L	M	D	I		
9	H	L	L	D	I	I	
10	M	H	H		D		I
11	M	H	M		D	I	I
12	M	H	L		D	I	
13	M	M	H			D	I
14	M	M	M				
15	M	M	L			I	D
16	M	L	H		I	D	
17	M	L	M		I	D	D
18	M	L	L		I		D
19	L	H	H	I	D	D	
20	L	H	M	I	D		
21	L	H	L	I	D	I	D
22	L	M	H	I	D		I
23	L		M	I	D	D	D
24	L	M	L	I	D		D
25	L	L	H	I		D	
26	L	L	M	I		D	D
27	L	L	L	I			D

TABLE I.   OPERATING CONDITION AND CONTROL RULES TABLE

There are 27 operating conditions totally. In TABLE I, K, n, p represent the deviations of the indexes. H (high)
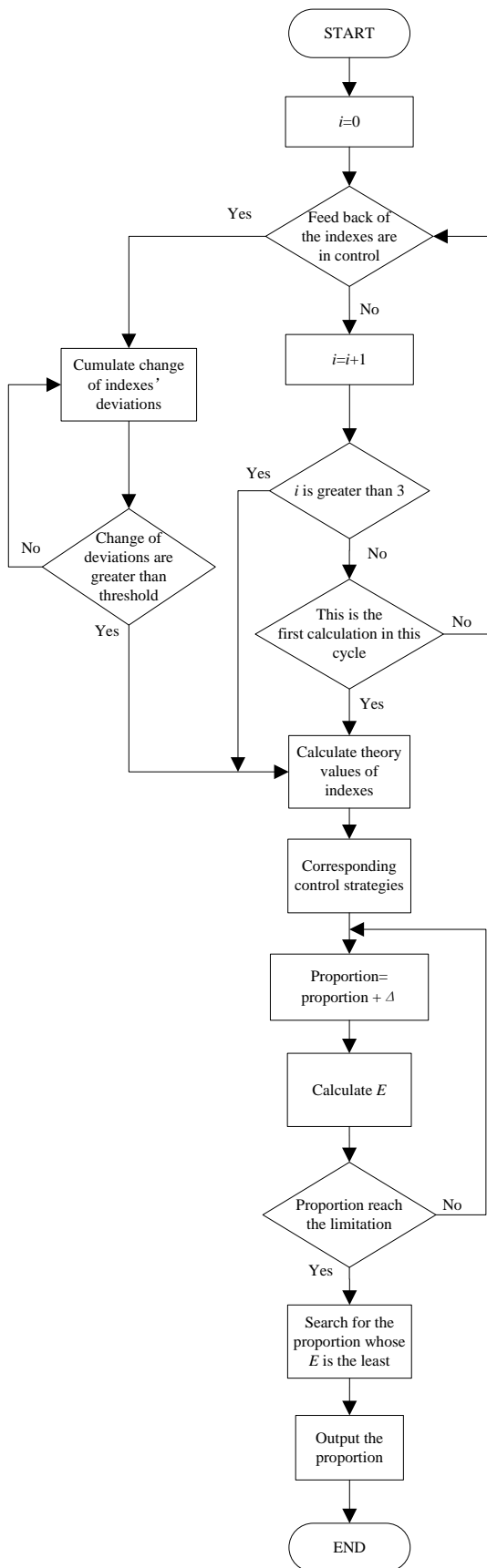
means the deviation is greater than positive threshold, M (moderate) means the deviation within set range and L(low) means the deviation is less than negative threshold. *C*, *S*, *A* and *F* represent the proportions of the four raw materials, and D, I represent decrease and increase of the proportions above. In each condition, values decreased are equal to values increased so that ensure the sum of proportions is 100%. In some cement enterprises, Proportion of Fe_2O_3 is controlled instead of *p*. The rules need a few adjustments.

Control algorithm process is shown in Fig. 2.

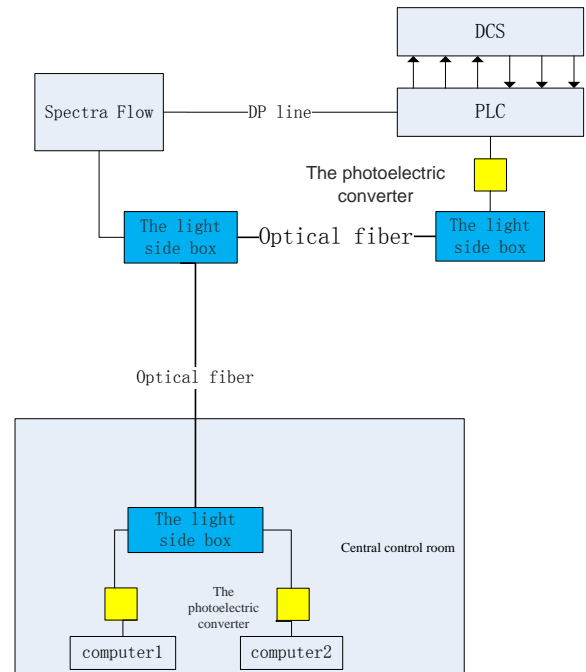## IV.   SYSTEM APPLICATION

Fig. 3.   System configuration

In the last part of the algorithm we minimize the "E" function values to guide the amount of change of raw material composition. The method currently in use is the incremental method in Fig.2. In the next version of the system a well-known optimization method, the Sequential Quadratic Programming (SQP) Method, is used. This method is used because it is the most efficient method for constrained local optimization. The convex nature of the minimum squared deviation function "E" allowed us to avoid using global optimization method, which is less efficient. The optimization problem can be formulated as the Non-Linear Programming problem below:

$$\min_{n} E$$
$$\begin{cases} n_1 + n_2 + n_3 + n_4 = 1 \\ lb_i \le n_i \le ub_i, i = 1,2,3,4 \end{cases}$$

Among them E is the cost function, lb and ub are lower and upper bound of the proportion of the raw materials respectively.

Fig. 2.   Flow Diagram of the Control Process

The SQP algorithm iteratively optimizes the cost function from a starting point input using the augmented Lagrangian method. The Lagrangian function of this problem is:

$$\mathcal{L}(n, \theta, \lambda, \sigma) = J(n) - \theta^T c(n) - \lambda^T lb(n) - \sigma^T ub(n)$$

Among them vector "c" is the equality constraint. "lb" and "ub" are boundary constraints.

MATLAB Optimization Toolbox is used to test the performance of the SQP algorithm on minimizing function "E". In 95% of the cases, the optimizer can be found within 20 iterations of quadratic equation solving. Therefore this method is more efficient in calculating the theoretical minimizer of the cost function "E" than the previous iterative incremental search method.

Based on the site conditions of one cement plant in Shandong province, the system configuration and communication network architecture are shown in Fig. 3.

In this system, the analyzer is located on the air-slide in the production site, and PLC lies in the electrical room of raw mill preparation workshop. PLC connects with the analyzer through PROFUBS-DP cable and DCS through I/O to realize data interaction of analyzer with control machine and DCS . In control room, there are two computers that connect with the analyzer and DCS through optical fiber respectively. Among them, computer 1 is used to analysis and computer 2 is used to control.

The main interface of control software is as follows.

Fig. 4.   Main interface of control software

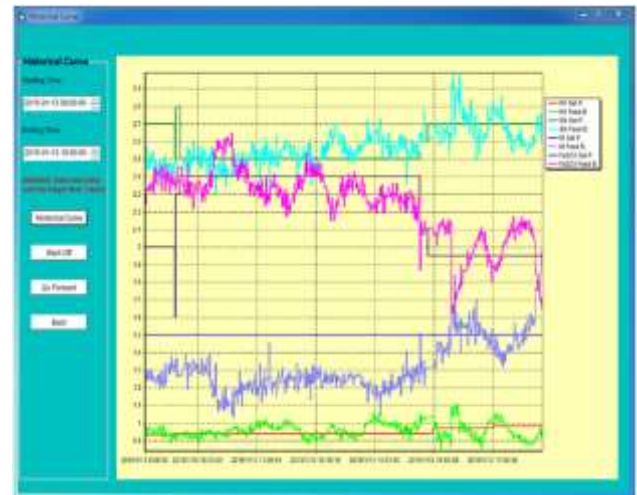The application curve is as follows.

Fig. 5.   The curve of the practical application

TABLE II.   LIME SATURATION COEFFICIENT CONTROL EFFECT DATA

K given	K feed back	K deviation	Lime-stone	Quartz sand	Mud-stone	Iron slag
0.94	0.938	-0.002	83.70	3.57	9.16	3.57
0.94	0.938	-0.002	83.99	3.43	9.15	3.43
0.94	0.929	-0.011	83.99	3.43	9.15	3.43
0.94	0.929	-0.011	83.98	3.65	8.95	3.42
0.94	0.929	-0.011	84.13	3.62	8.86	3.39
0.94	0.92	-0.020	84.33	3.56	8.72	3.39
0.94	0.946	0.006	84.51	3.51	8.59	3.39
……	……	……	……	……	……	……
0.94	0.936	-0.004	83.09	3.52	9.91	3.48
0.94	0.948	0.008	83.09	3.52	9.91	3.48
0.94	0.948	0.008	82.59	3.52	10.28	3.61
0.94	0.936	-0.004	82.59	3.52	10.28	3.61
0.94	0.936	-0.004	82.87	3.52	10.07	3.54
0.94	0.943	0.003	82.68	3.70	9.79	3.83

TABLE III.   SILICON RATE CONTROL EFFECT DATA

n given	n feed back	n deviation	Lime-stone	Quartz sand	Mud-stone	Iron slag
2.50	2.57	0.07	83.70	3.57	9.16	3.57
2.50	2.57	0.07	83.99	3.43	9.15	3.43
2.50	2.40	-0.10	83.99	3.43	9.15	3.43
2.50	2.40	-0.10	83.98	3.65	8.95	3.42
2.50	2.40	-0.10	84.13	3.62	8.86	3.39
2.50	2.55	0.05	84.33	3.56	8.72	3.39
2.50	2.41	-0.09	84.51	3.51	8.59	3.39
……	……	……	……	……	……	……
2.50	2.49	-0.01	83.09	3.52	9.91	3.48
2.50	2.49	-0.01	83.09	3.52	9.91	3.48
2.50	2.49	-0.01	82.59	3.52	10.28	3.61
2.50	2.49	-0.01	82.59	3.52	10.28	3.61
2.50	2.49	-0.01	82.87	3.52	10.07	3.54
2.50	2.48	-0.02	82.68	3.70	9.79	3.83

TABLE IV. Fe_2O_3 CONTROL EFFECT DATA

International Journal of Advances in Computer Science & Its Applications– IJCSIA
Volume 5 : Issue 2   *[ISSN : 2250-3765]*

Publication Date: 30 October, 2015

Fe_2O_3 given	Fe_2O_3 feed back	Fe_2O_3 deviation	Lime-stone	Quartz sand	Mud-stone	Iron slag
2.40	2.37	-0.03	83.70	3.57	9.16	3.57
2.40	2.37	-0.03	83.99	3.43	9.15	3.43
2.40	2.48	0.08	83.99	3.43	9.15	3.43
2.40	2.48	0.08	83.98	3.65	8.95	3.42
2.40	2.48	0.08	84.13	3.62	8.86	3.39
2.40	2.28	-0.12	84.33	3.56	8.72	3.39
2.40	2.37	-0.03	84.51	3.51	8.59	3.39
……	……	……	……	……	……	……
2.40	2.37	-0.03	83.09	3.52	9.91	3.48
2.40	2.30	-0.10	83.09	3.52	9.91	3.48
2.40	2.30	-0.10	82.59	3.52	10.28	3.61
2.40	2.37	-0.03	82.59	3.52	10.28	3.61
2.40	2.37	-0.03	82.87	3.52	10.07	3.54
2.40	2.35	-0.05	82.68	3.70	9.79	3.83

The statistical tables of the control results are as above (this application is based on K, n and Fe_2O_3).As the data show in TABLE II - TABLE IV, percent of pass of K is 85%, n is 89% and Fe_2O_3 is 83%.

V.   CONCLUSION

This system combines theoretical calculations, artificial experience and incremental optimization to form a unique control strategy which can deal with the large fluctuation of raw material in various conditions. The quality of raw mill control is improved. In addition, the online analyzer with NIR technology which this control system bases on is safer for operators. The actual application of the system in a Cement enterprise proves the system's control quality and efficiency.

VI.   ACKNOWLEDGEMENT

[1]   Basic knowledge of modern cement production revision issue, J.Cement, pp.10-51, 2014.

[2]   K J. Fan,X M. Jin, "The overview about the control process of cement raw mill's proportioning," Journal of Portland,vol.27,no.4,pp.759-764,2008.

[3]   S J. Xu, "The research of cement raw mill proportioning system's application," University of science and technology of shandong,2006 .

[4]   K Ayhan and C zsoy ,"Identification and control of the raw material blending process in cement industry," Int JAdapt Control Signal Process , 2004.

[5]   X P. Cao,X H. Chen and H Y. Zhang, "Use D-D neutron generator measurement the element's content in cement's raw mill," Atomic energy science and technology, vol.45,no.1,pp.108-111,2011.

[6]   R S. Zhang, "Rate assistant research of automatic blending control system," Cement,vol.4,pp.50-53,2007.

[7]   China Cenent Association of Canada United States tours, "Characteristics of online analyzer used in the cement industry-china cement association to the United States- Canada Cement equipment survey report,*"* J. China Cement,vol.5,pp.23-24,2004.

[8]   H B.Yu,X G.Wu and M Z. Fan,"An optimizing control method about raw value in raw mill proportioning system" Chinese 200710158921.0,Jun 2009．

[9]   C. Bányász, L. Keviczky and I. Vajk, "A novel adaptive control system for raw material blending," IEEE Control Systems Magazine. 2003.

[10]   R P. Xing, X H. Wang and T. Shen, "Study on cement raw materials proportioning based on least square algorithm," Industrial control computer,vol.20,no.5 ,pp.47-48,2007.

About Author (s):

Dr Yu Hongliang Received PhD in Control Engineering From Northeastern University of China. He is now the Associate Professor in University of Jinan and his research interests includes advanced control theory and application.

Mr Wan Xin received his Bachelor of Science in Control Engineering in Shandong Normal University and is currently undertaking a Master of Science in Control Engineering in University of Jinan,

Mr Lian Guodong is currently undertaking a Master of Science in Control Engineering in University of Jinan,

Mr Duo Wang is currently studying BEng in Electronic and Information Engineering in Imperial College London and he also serves as student researcher in the Department of Electronic and Electrical Engineering, Imperial College London

Prof. Wang Xiaohong received PhD in Control Engineering from Northeastern University, China. He is now the head of Automation Reseach Lab in University of Jinan. He also serves as Visiting Scholar in the Chinese Academy of Science. He received various awards including "outstanding researchers of Shandong Province". His research interests include advanced control theory and application, and usage of state-of-the-art online sensors for optimal control of industrial plants.