DISTRIBUTED CONTROL FOR CEMENT PRODUCTION
OF VERTICAL SHAFT KILN

XIAOHONG WANG, QINGJIN MENG, HONGLIANG YU,
ZHUGANG YUAN, AND XINHE XU

Abstract. The distributed control for cement production of vertical shaft kiln VSK is presented in this paper. The system consists of operator station, engineer station, process station and communication networks. The detailed makeup and functions are also described. Then the process flows and distributed control functions of cement production line of VSK are introduced. Hereinto, as the most important link, the control for sintering process of VSK is emphasized. A fuzzy method is given. Such systems have been applied in some plants for over 1 year. High quality assurance and cost-effectiveness have both been achieved through such powerful automation systems.

Key Words. distributed control, cement production, vertical shaft kiln, fuzzy control.

1. Introduction

As a result of increasing competition, there is a growing tendency to improve production quality, environmental protection and management cost-effectiveness in cement plants. But outdated automation system (only analogue instruments) apparently can’t meet with these demands. Then distributed control system is adopted to complete the control functions that include basic automation, the optimization control for process, management formation automation for workshop, fully automatic control for laboratories, and so on. We use the DCS product of ABB – Industry IT control system[1] as the foundation platform, which use the information flow as the key part of system integration and which can realize most of management and control functions for cement production of VSK.

2. Model structure and functions of the distributed control system

The structure of the Industry IT system is demonstrated as Figure 1. From the top down, the DCS mainly includes four parts: engineer station (ES), operator station (OS), process station (PS) and communication networks. The engineer station and the operator stations mainly perform the centralizing control and management functions. The process stations perform the distributed control functions of each sub-system of VSK production line. Communication networks perform the communication functions among all the kinds of stations. The detailed structure and functions are described next.

Received by the editors June 1, 2004 and, in revised form, January 22, 2005.
2.1. **Operator station.** In general, there are 3-4 operator stations in one distributed control system, by which the operators of plants can supervise the real-time state of the cement production line of VSK, and can make essential manipulation to control the process flow.

The hardware platform of operator station is the general IPC (industrial personal computer). The development platform of software is DIGIVIS, which runs under the win2k environments. The functions of these operator stations are configured by the engineer station and can make hot backup each other. The detailed functions are:

- Displaying the process flow diagram of the production line. Each device is diagramed with the graphic figure, and the working state of the device can be displayed by means of the real-time information collected from process stations. The operator can manipulate the device to control process flow by means of clicking these graphic figures.
- Building, displaying, and printing the reports of the production line. The contents of the report include the manipulation log, product log, and so on.
- Displaying and sounding the alarm information. All kinds of abnormal status are alarmed, which include the process abnormality, the errors of DCS, the faults of equipments, and so on.
- Storing, displaying, and printing the historical data. In general, the historical data is configured to store 3 seasons (90 days), and displayed in the shape of curve.

2.2. **Engineer station and configuration software.** There are only one engineer station in the distributed control system, by which the system engineer can configure the whole system, program the control program, supervise and debug the running of the program.
The hardware platform of operator station is also the general IPC (industrial personal computer). The development platform of software is DIGITOOL, which runs under the win2k environments. The detailed functions are:

- Configuring the system. Structure of the hardware. All hardware units of the DCS are configured in engineer station. The contents include the configuration of the quantity of OS, the type of the gateway, the quantity and type of the PS, and so on.
- Programming the control program. According to the demand of the process flow, all the programs are programmed in the engineer station to finish the control functions of every sub-system of the cement production of VSK.
- Revising parameters of system time. In the DCS, all sampling times are gained directly from computer’s clock. Owing to existing errors, the computer’s clock is not always accurate. Then the system engineer can correct the system clock by engineer station timely.
- Setting parameters of communication. In the system, this function lets users define I/O controls such as communication protocol, baud rate, character length, stop bits, parity and buffer size for all installed ports. When process station is changed, these parameters and port number could be redefined. Consequently, the system has great flexibility.
- Supervising the running of the control program.

2.3. Process station. According to the process flow, there are totally 3 process stations in the DCS to complete the distributed control functions of the whole VSK production line. In general, the process stations call raw-material station, VSK station, and cement station.

Hardwares have two kinds. One is AC800F controller, which is the ‘brain’ of the process stations. All program for each sub-system of the cement production line run in the controller. The other kind of hardware is the I/O modules, which is the ‘eyes’ and ‘hands’ of the process station. The detailed functions are:

- Running the control program in the controllers. ALL the functions of distributed control of each sub-system is completed.
- Collecting the real-time data. All the field-data is measured by instruments and sent to the I/O modules.
- Interchanging the real-time data. The controllers receive and access the data collected from the I/O modules. and then, according to the demands of product field, the proper data or orders are interchanged among the controllers, the I/O modules, the operator stations and the engineer station by means of communication networks.
- Monitoring the running status of the DCS own.

2.4. Communication networks. Communication networks provide ability to connect the managing and the managed, the controlling and the controlled. To effectively communicate with each other among the engineer station, operator stations and process stations, the communication networks is partitioned into two layers-system networks and fieldbus networks.

- System networks complete the communication functions among the engineer station, operator station and the controller of the process station. The
communication protocol of this layer is TCP/IP. Every unit in this network has fixed address. The medium of this network is optical fiber.

- Fieldbus networks complete the communication functions between controller and I/O modules in each process station. The communication protocol of this layer is profibus. The medium of this network is communication cable.

3. Process flow and process control of cement production line

3.1. VSK process flow. The whole process of cement shaft kiln production is a huge and complicated system. There are many sub-systems in the process flow of VSK. The simple structure of VSK process flow is demonstrated in Figure 2.

![Figure 2. Process flow of cement plant of VSK](image)

It has been described that there are totally 3 process stations to complete the distributed control functions. They are raw-material station, VSK station, cement station.

In general, the raw-material station control the sub-systems such as the storage system of raw materials, the proportioning system of raw-material to desired fineness, the mill system of raw-material, and the homogenizing system to obtain raw meal. The VSK station control the sub systems, such as the system of pre-watering granulatingthe system which charge nodules into the vertical shaft kiln through rotary distributor, the VSK system which calcine raw-material to sintering clinker, the mill system of coal. The cement station control the sub-systems, such as storage system of sintering clinker, proportioning system of sintering clinker mixed with gypsum to desired fineness, the mill system of sintering clinker, and the cement packet system.

In the following, the control functions of some main sub-systems are described in detail.
3.2. Control of raw-material proportioning system. The raw materials to be mixed in cement production have 5-8 kinds. The most important component is limestone. Some others are bat chalk, clay, shale, quartz, sand, iron ore, pyrite or blast furnace slag, and so on. These materials must be well blended before they are grounded in the mill of the raw-material.

These raw materials are fed by weigh-feeders, which are controlled by local computers. On the basis of the prescription sent by DCS, the feeders are automatically adjusted according to the special control algorithm, and the results are communicated to the DCS by means of profibus networks.

This kind of control mode can reduce both the complexity of programming and the cost of whole control system.

3.3. Control of the pre-watering granulating. High quality pre-watering granulating could be guaranteed when they are controlled automatically by DCS. It could stabilize sintering zone and adjust deflected burning in the sintering process of VSK, then the thermal regulation of sinter of VSK could be stabilized, and both production quantity and production quality could be guaranteed. Finally energy consumption could also be further reduced.

3.3.1. Principle of control system of the pre-watering granulating. In order to realize the water’s automatical following of raw material, the ratio control system of double closed-loop is adopted in the process of pre-watering granulating. The rate of water flow follows the change of raw material flow automatically according to the given ratio of water and raw material.

3.3.2. The realization of control scheme and control algorithm. Control system of the pre-watering granulating is a typical ratio control system. The granularity of raw material ball must be well distributed (in general, φ10 mm or so), and the rigidity of the granularity needs to be moderate. Considering the technology of the pre-watering granulating, we choose the scheme of double closed loop ratio control system demonstrated in Figure 3. The flow rate of raw material is taken as the main flow, the flow rate of water is the vice flow rate which is determined according to the flow rate of raw material. The control closed loop of the main flow rate could ensure the stable change of main flow according to the target of the given value, the control closed loop of the vice flow rate could ensure the vice flow rate follows the main flow rate according to the given ratio. Because of the fluctuation of the raw material flow rate in the production of VSK (from 0 kg/s to 800 kg/s) and the difference of water quantity in raw material, the target value of raw material flow rate and the ratio of raw material and water should be set according to practical requirements. In addition, there exists nonlinear factors in the actuator such as water pump, and time delay in the raw material transferring links. In order to ensure the quality of control, PI control is adopted in both the main controller and the vice controller. For the sake of avoiding "resonance", when the change frequency of main flow is near to the working frequency of vice loop the parameter of main controller should be adjusted to let main variable change non-periodically. Whereas vice control loop is a trace control system, vice-variables must change rapidly and precisely to follow the main flow according to the given ratio, and the over shooting is not permitted to occur, so the parameters of vice-controller should be set to let
vice-variable satisfy the critical process between oscillation and non-oscillation.

Figure 3. Control system structure of the pre-watering granulating

3.4. Control of the sintering process of VSK. The sintering process of VSK is the key link for cement production of VSK. But the sintering process of VSK is an multivariable, time-varying, coupling, delay, and nonlinear system. It is very complicated and difficult to establish the accurate model with the pure mathematical method. At present, owing to the complicated technology, strong disturbance and repeated controlling operation, the control manner strongly depends on the estimation, experience and sense of responsibility of the worker, thus the regulating quality is very unstable. Hence, a fuzzy control project of cement shaft kiln is proposed to solve these problems.

3.4.1. Fuzzy definition of the burning zone state. In the sintering process of VSK, the position and the status of sintering zones are the decisive factors for the sintering of clinker. Deflected burning could lead to unstable state of VSK. Sometimes jet fire might be caused.

Centering upon sensing sintering zone and aiming at stabilizing sintering zone state and avoiding the occurrence of deflected burning, we’ve selected 9 key parameters as the control variables, which include upper layer kiln lining temperature, lower layer kiln lining temperature, clinker temperature, waste gas temperature, blowing pressure, blowing flow rate, discharge speed, opening degree of bottom blowing valve, and opening degree of peripheral blowing valve. Among them, the former 6 variables are detected variables, and the later 3 are manipulated variables.

The framework of the kiln computer fuzzy control scheme can be demonstrated in Figure 4.

According to the process of cement shaft kiln and the experience of the worker, the fuzzy domain of the controlled variables is [-10, +10], which is divided into 21 grades, and the corresponding fuzzy subset is LOW, OK, HIGH. The manipulated
The variables domain is the same as the controlled ones, the corresponding fuzzy subset is negative large, negative middle, negative small, negative zero, zero, plus zero, plus small, plus middle, plus large, or NL, NM, NS, N0, 0, P0, PS, PM, PL in short.

Based on the experience of workers and the selected controlled variables, six variables are taken as the elements for the definition of sintering zone. The elements here refer to the average temperatures of upper kiln lining $T_{sp}$ and lower kiln lining $T_{xp}$, the temperatures of waste gas $T_f$ and clinker $T_s$, the difference between the highest and the lowest temperatures of the upper layer $T_{sc}$, and the lower layer $T_{xc}$ respectively, i.e.,

$$T = \{T_{sp}, T_{xp}, T_f, T_s, T_{sc}, T_{xc}\}.$$

Taking the description of the checked variables and the selected fuzzy subsets into account, we define the fuzzy subsets of the above variables as follows: $T_{sp}, T_{xp}, T_f, T_s$: \{LOW, OK, HIGH\}; $T_{sc}, T_{xc}$: \{OK, HIGH\}. Then the model of the sintering zone state can be defined as $T = \{T_{sp}, T_{xp}, T_f, T_s, T_{sc}, T_{xc}\}$. Therefore, the fuzzy definition of typical sintering zone state is shown in Table 1.

**3.4.2. Fuzzy identification of the sintering zone state.** The model of the sintering zone state $T$ is a 6-element model. Because $T_{sp}, T_{xp}, T_f,$ and $T_s$ are allowed to take three fuzzy values: LOW, OK, HIGH, whereas $T_{sc}, T_{xc}$ take two fuzzy values: OK and HIGH, there are altogether $3^4 \times 2^2$ states. However, some states never appear, and some states can be synthesized by some typical states. According to the experience, the above 14 sintering zone states are taken as the research objects after optimization.

DH represents the set of the sintering zone state and $dh$ represents the specific configuration, where 1-14 correspond to each sintering zone state, i.e., $DH=\{dh | dh= 1,2,3,4,5,6,7,8,9,10,11,12,13,14\} = \{\text{normal sintering zone, superior sintering zone, inferior sintering zone, high temperature sintering zone, low temperature}\}$.  

![Figure 4. The framework of the kiln computer fuzzy controlled scheme](image)
Table 1. The fuzzy definition of typical sintering zone state

<table>
<thead>
<tr>
<th>T</th>
<th>T_sp</th>
<th>T.fp</th>
<th>T_f</th>
<th>T_s</th>
<th>T.sc</th>
<th>T.xc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal sintering</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Superior sintering</td>
<td>HIGH</td>
<td>LOW</td>
<td>HIGH</td>
<td>LOW</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Inferior sintering</td>
<td>LOW</td>
<td>HIGH</td>
<td>LOW</td>
<td>HIGH</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>High temperature sintering</td>
<td>HIGH</td>
<td>LOW</td>
<td>HIGH</td>
<td>LOW</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Low temperature sintering</td>
<td>LOW</td>
<td>LOW</td>
<td>HIGH</td>
<td>HIGH</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Thick sintering</td>
<td>HIGH</td>
<td>HIGH</td>
<td>LOW</td>
<td>LOW</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Superior thick sintering</td>
<td>HIGH</td>
<td>OK</td>
<td>HIGH</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Inferior thick sintering</td>
<td>OK</td>
<td>HIGH</td>
<td>OK</td>
<td>HIGH</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Thin sintering</td>
<td>LOW</td>
<td>LOW</td>
<td>LOW</td>
<td>LOW</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Superior thin sintering</td>
<td>OK</td>
<td>HIGH</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Inferior thin sintering</td>
<td>LOW</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Superior deflected burning</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>HIGH</td>
<td>OK</td>
</tr>
<tr>
<td>Inferior deflected burning</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>HIGH</td>
</tr>
<tr>
<td>Central pillar sintering</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>HIGH</td>
<td>OK</td>
<td>OK</td>
</tr>
</tbody>
</table>

Sintering zone, thick sintering zone, superior thick sintering zone, inferior thick sintering zone, thin sintering zone, superior thin sintering zone, inferior thin sintering zone, superior deflected burning, inferior deflected burning, central pillar sintering zone.

A table of fuzzy subsets in the domain of controlled variables and the manipulated variables is built, and the degree of membership of every fuzzy subset follows normal distribution in the corresponding basic domain:

\[ \mu(x) = 1 - \exp\left(-\frac{a}{|c-x|}b\right). \]

Where a, b, c are constants for a certain fuzzy subset.

For any group of checked variables, \( T=\{x_1, x_2, x_3, x_4, x_5, x_6\} \) can be obtained, in which every \( x_i (i = 1 - 6) \) can be mapped to \([-10, +10]\), and the degree of membership of \( x_i \) to fuzzy subsets can be obtained from membership equation (1). It has been described that various sintering zone states can be defined with the fuzzy terms in corresponding domains of various checked variables. Now, replacing the degrees of membership of the various fuzzy terms with various checked variables, we could obtain a new vector \( Y_j \) (j stands for j-th sintering zone state). \( Y_j \) can fully embody the membership properties of checked variables of j sintering zones of this group. The degree of membership should be determined by the extent to which various sintering zone states attach importance to various checked variables.

Assume that \( \mu_j(X) \) stands for the degree of membership of vector X to j sintering zone, \( Y_j = (y_{ij}) \) (where \( y_{ij} \) stands for the degree of membership of checked variable \( x_i \) to i-th fuzzy subset in j sintering zone state). Then

\[ \mu_j(x) = \begin{cases} 
\frac{y_{1j} \land y_{2j} \land y_{3j} \land y_{4j} \land y_{5j} \land y_{6j}}{\alpha_{1j} + \alpha_{2j} + \alpha_{3j} + \alpha_{4j} + \alpha_{5j} + \alpha_{6j}}, & j=1,14; \\
\frac{\alpha_{1j} \land (y_{1j} \land y_{2j} \land y_{3j}) + \alpha_{2j} \land (y_{1j} \land y_{2j} \land y_{4j}) + \alpha_{3j} \land (y_{1j} \land y_{2j} \land y_{5j}) + \alpha_{4j} \land (y_{1j} \land y_{2j} \land y_{6j})}{\alpha_{1j} + \alpha_{2j} + \alpha_{3j} + \alpha_{4j}}, & j=[2,13]. 
\end{cases} \]

Where \( \alpha_{ij} \) (j=1-14, i=1-4) are weight coefficients.

It should be pointed out that the determination of \( \mu_j(X) \) is closely related to the practical experience. Take a cement factory in Shandong province for example,
the obtained $\alpha_{ij}$ values are shown in table 2. With $\mu_j(X)$, we could determine the sintering zone state represented by vector $X$.

Table 2. The values of weight coefficients-$\alpha_{ij}$

<table>
<thead>
<tr>
<th>$i$</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0.4</td>
<td>0.4</td>
<td>0.2</td>
<td>0.2</td>
<td>0.8</td>
<td>0</td>
<td>0.5</td>
<td>0.8</td>
<td>0.5</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1.0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.1</td>
</tr>
</tbody>
</table>

3.4.3. Design of fuzzy controller. Considering the processing principles of various sintering zone states and the experience of actual operation, we get the fuzzy controlling rules by optimizing as shown in table 3.

The controlling rules of 14 sintering zone states have been obtained in table 3. As for the states besides the 14 states, they are generally based on the above 14 rules to derive the corresponding fuzzy manipulated variables. However, it is laborious to construct the fuzzy relations of the 14 rules, and it is also a hard work to do the calculation before every controlling operation, thus it is not practical for timely control.

As we know, the membership functions of the controlling operations in controlling rules are represented approximately with a $21 \times 1$ matrix, in which 21 elements are obtained from membership equation 1.

For every manipulated variable, the effect of fuzzy controlling rules is a controlling operation expressed by membership function. Whether the controlling behavior determined by the controlling rules is fully effective at the present state depends on the approximation relationship between the present state and the conditions of the rule. Therefore we estimate the contribution of the controlling behavior of the $i$-th rule to the present controlling behavior of sintering zone state by the following formula:

\begin{equation}
\mu_{\delta R}^{(j)} = C_j \ast \mu_j(X),
\end{equation}

where $C_j$ stands for the degree of membership of the present state to this rule, $\mu_j(X)$ is a $21 \times 1$ matrix of the basic terms determined by the controlling part of this rule, $\mu_{\delta R}^{(j)}$ is the contribution made by the controlling behavior of this rule to the controlling behavior of the present state, which, standing for the membership function of the controlling behavior, is also a $21 \times 1$ matrix.

The controlling behavior obtained by the estimation according to the typical membership function of $n$ controlling rules is established after the synthesis with “OR” operation upon the results for every rule, i.e.

\begin{equation}
\mu_{\delta R} = \mu_{\delta R}^{(1)} \lor \mu_{\delta R}^{(2)} \lor \ldots \lor \mu_{\delta R}^{(n)}.
\end{equation}

In the present system, $n = 14$, $C_j = j(X)$. For example, $\mu_1(X) = 0.9, \mu_2(X) = 0.2, \mu_j(X) = 0 (j = 3 - 14)$, considering table 3 and the following membership function of the discharge controlling quantity obtained from (4), $\mu_{\delta R} = 0.9 \ast \mu0 \lor 0.2 \ast \mu PL \lor 0.0 \ast \mu NS \lor \ldots \lor 0.0 \ast \mu NL$; the membership function of the bottom
Table 3. The fuzzy controlling rules

<table>
<thead>
<tr>
<th>Sintering zone State</th>
<th>Discharge Control</th>
<th>Bottom Blowing Control</th>
<th>Peripheral Blowing Control</th>
<th>Manual Control*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal sintering zone</td>
<td>0</td>
<td>P0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Superior sintering zone</td>
<td>PL</td>
<td>0</td>
<td>PS</td>
<td>Increasing dust feeding</td>
</tr>
<tr>
<td>Inferior sintering zone</td>
<td>NS</td>
<td>PL</td>
<td>0</td>
<td>Decreasing dust feeding</td>
</tr>
<tr>
<td>High temperature sintering zone</td>
<td>0</td>
<td>NS</td>
<td>0</td>
<td>Notifying decrease of coal feeding</td>
</tr>
<tr>
<td>Low temperature sintering zone</td>
<td>0</td>
<td>PS</td>
<td>0</td>
<td>Notifying increase of coal feeding</td>
</tr>
<tr>
<td>Thick sintering zone</td>
<td>PM</td>
<td>PL</td>
<td>0</td>
<td>Improve fineness of coal powder</td>
</tr>
<tr>
<td>Superior thick sintering zone</td>
<td>PL</td>
<td>P0</td>
<td>0</td>
<td>Improve fineness of coal powder</td>
</tr>
<tr>
<td>Inferior thick sintering zone</td>
<td>NM</td>
<td>PL</td>
<td>0</td>
<td>Improve fineness of coal powder</td>
</tr>
<tr>
<td>Thin sintering zone</td>
<td>PS</td>
<td>PM</td>
<td>0</td>
<td>Impair fineness of coal powder</td>
</tr>
<tr>
<td>Superior thin sintering zone</td>
<td>PM</td>
<td>PS</td>
<td>0</td>
<td>Impair fineness of coal powder</td>
</tr>
<tr>
<td>Inferior thin sintering zone</td>
<td>0</td>
<td>PS</td>
<td>0</td>
<td>Impair fineness of coal powder</td>
</tr>
<tr>
<td>Superior deflected burning</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>Blowing, filling cavity, drawing fire</td>
</tr>
<tr>
<td>Inferior deflected burning</td>
<td>0</td>
<td>PS</td>
<td>PL</td>
<td></td>
</tr>
<tr>
<td>Central pillar sintering zone</td>
<td>NL</td>
<td>P0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

* - Presently manual control is needed in some states

blowing controlling behavior is \( \mu_{SR} = 0.9 \ast \mu_{P0} \lor 0.2 \ast \mu_{P0} \lor 0.0 \ast \mu_{PL} \lor \ldots \lor 0.0 \ast \mu_{P0} \); Since the degree of membership of the present state to sintering zone state 1 is 0.9, the manipulated variable of the 1st rule is the main choice, at the same time the effect of the 2nd rule is also considered, as for the other rules, they do not play any role at all.

The controlling quantity obtained from the above is a matrix of membership functions, of which the precision of controlling operation is the value of corresponding horizontal axis of area under halving \( \mu_{SR} \) curve, i.e., we perform decision-making with the method of barycenter.

Due to the slow change of temperature signals and the fast change of blowing pressure, blowing flow rate, and the sampling periods are selected as 60s and 1s respectively. In order to remove noise, 60 groups of data of temperature signals are used in every sampling period with one second between two periods, and are
taken as sampled data after proper treatment; as for the signals of blowing pressure blowing flow rate. The 10 data consecutively sampled each time are taken as the sample data after being treated properly. According to the sampled data, the production process is monitored and controlled, and alarm can be given in time.

3.5. Control of clinker-material proportioning system. The clinker mixed with gypsum and other materials is grounded in the cement mill to produce cement. The control algorithm is the same as raw materials proportioning system.

3.6. Control of chemical lab management system. The component of materials in every link of production chain is analyzed by local computers, and the statistic findings are communicated to DCS to guide the production of all the workshops.

4. Conclusion

The distributed control system of cement production has been applied to some vertical shaft kiln plants. The applications prove that the system can successfully realize control and management functions of production process of VSK plants. The quality of clinker is improved by 20-30 percent, and free lime is decreased. The output of one shaft kiln is increased by 15 percent or so, and 2.87 KWh of electricity can be saved per ton of clinker. On the basis of these, it synchronously improved quantity and quality of cement production, decreased intensity of labor, and decreased energy consumption. Consequently the control system is beneficial in both economic and social aspects.

References


School of information science and engineering, Jinan University, Shandong, 250022, PRC E-mail: wxh_auto@sina.com.cn and hengtech@163.com

School of information science and engineering, Northeastern University, Liaoning, 110004, PRC E-mail: ziliu@163.com

School of information science and engineering, Jinan University, Shandong, 250022, PRC E-mail: cse_yzg@ujn.edu.cn

School of information science and engineering, Northeastern University, Liaoning, 110004, PRC E-mail: xuxinhe@163.net