**Article ID**: 1003 - 6326(1999)03 - 0651 - 04

# Design and development of expert system for controlling sintering process[①]

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**Abstract:** The general structure of expert system for controlling sintering process has been proposed. It includes knowledge base, inference engine, data acquisition system, learning system, knowledge base management system, explanation system and so on. The control functions consist of sintering chemical composition control centered on basicity and sintering process state control centered on permeability. The adaptive prediction of sintering chemical composition, the control strategy centered on basicity, the control strategy centered on permeability, the judgement of permeability and the prediction of burn through point were studied. The software of system, which includes about 1 000 expert rules, was successfully applied in off-line control of sintering process in a sintering plant.

**Key words**: sintering; expert system; process control **Document code: A**

## 1 INTRODUCTION

For a long time, the sintering process has been controlled mainly depending on operators' experience. The control of sintering process is based on real-time production data, i.e. raw materials parameters, operation parameters, equipment parameters, state parameters and index parameters. Some of these parameters are acquired by on-line test, others are acquired by chemical analysis. Because of the time-lag and fluctuation of data acquisition, and the difference of operators' operation knowledge, decision ability, responsibility and so on, manual operation inevitably results in the fluctuation of operation control, and then the production is influenced. Especially, with the development of large-scale sinter equipment, this influence is greater. The sintering mathematical models can only be used to predict some of the process parameters and control a part of the sintering process because of the complicated mechanism and the related influence factors[1~4]. It is difficult to control the whole sintering process, but expert system developed rapidly starts a new way for the control of sintering process.

Expert system is first applied in a sintering plant of Japan at the beginning of 1980's. At present, it is used extensively abroad. In Japan, the Chiba plant of Kawasaki Steel Corp developed the operation guide system (OGS)[5] which includes sintering energy control system, feeder gate control system and chemical composition control system; its application reduced the breeze consumption, and steadied the operation. Also in Japan, the Kawasaki Steel Corp developed a diagnosis expert system which contains BTP (Burn Through Point) control, equipment protection and quality and quantity control and includes 500 rules; the application of this system reduced the fluctuation of BTP and stabilized the sinter quantity. Moreover, the Nippon Steel Corp in Japan developed a sintering expert system, and the Newcastle and Port Kembla sintering plant in Australia built an expert system on the basis of the development tools SHERPA and TABLEAUX[6].

① Project 59474005 supported by the National Natural Science Foundation of China
Received Apr. 30, 1999; accepted May 28, 1999

## 2 GENERAL STRUCTURE OF SYSTEMS

Knowledge base and inference engine are the principal components of expert system[7]. Production data are the basement of the control of sintering process, so the data acquisition system has special function in the system. Besides, a perfect expert system should include man-machine interface system, learning system, knowledge base management system and explanation system[8]. The general structure of system is shown as Fig. 1.

**Fig. 1** General structure of system
Solid line —Information stream;
Dotted line —Control stream

The general control mode is an interface control system. Users can manage the process control system, knowledge management system and system help by selecting menus. The process control system is the main mode of system, it manages every sub-system through the control organization and exchanges information among the sub-systems with a blackboard. The data acquisition system acquires appropriate information from the blackboard according to the orders sent out by control organization and provides appropriate data acquisition platform. The data acquired are transferred to the blackboard. The prediction system of chemical composition acquires production data when the control organization starts. On the basis of present production data the system modifies the models' parameters to suit the change of sintering process, and predicts the contents of sinter chemical composition in the future by the modified predictive models. The predictive informations are transferred to the blackboard. The control systems of chemical composition and process state choose the suitable knowledge base and save the knowledge in the blackboard when the control organization starts. According to the production data and knowledge acquired from the blackboard, control system chooses the suitable inference engine, judges the production states, analyzes the reasons, and gives the qualitative and quantitative control guidance. In the inferring process, the medium information and inferred results are transferred to the blackboard and the learning system and explanation system are loaded. The learning system adds or modifies the knowledge of knowledge base based on the information of blackboard when the conclusion can not be inferred or the inferring conclusions are wrong in the inferring process of the control system for chemical composition or for process state. The explanation system explains the inferring process of control system of chemical composition or the process state in order to raise the system's transparence. The knowledge management system gives the tool for building, editing and modifying the knowledge base, which accelerate the development of expert system for controlling sintering process.

## 3 CONTROL FUNCTION OF SYSTEMS

### 3.1 Sintering chemical composition control centered on basicity

#### 3.1.1 Adaptive prediction of sinter chemical composition

Sintering process is a dynamic and complicated system. The theoretical model for controlling sintering chemical composition is complex and difficult to calculate, so it is unfit for on-line control. Therefore, according to modern control theory, when observing and analyzing problem, the complex interior theory is put aside, and the sintering process is considered as a "grey box" system. On the basis of a number of time-changeable production data acquired, the time series models are built, in which the method of system identification is used. The process dynamic characteristics must be displayed by its changeable data, so the model parameters are adjusted based on these data to fit the system time-change. The adaptive predictive models are established, and used to predict sintering chemical compositions (TFe, $SiO_2$, CaO, MgO, and FeO) and the basicity ($R$), quantitatively.

3.1.2 Control strategy centered on basicity

It is ideal that all chemical compositions realize optimal conditions simultaneously, but it is almost impossible to optimize every chemical composition at the same time because of the high relativity and random variation of chemical compositions. So there must be focal point to control the chemical compositions.

At present, most blast furnace burden structure is high-basicity major sinter and a few acid pellet or coarse ore. The optimal basicity or optimal basicity scale of sinter and pellet are determined by experiment. The proportions of sinter and pellet are decided by the demands of blast furnace slag basicity, equipment capacity and raw materials supply. So the undulation of sinter $R$ affects the normal production of blast furnace irresistibly, and the fluctuation of $R$ influences the pelletization for satisfying the demands of blast furnace slag basicity. Relatively, the Fe contents of blast furnace burden are not so strict as $R$, and it can be regulated by coke loading. As a result, the control strategy of sinter chemical composition centered on $R$ is proposed for steadying the blast furnace production.

The control strategy centered on $R$ is that sinter $R$ is controlled prior to others such as sinter chemical compositions, which implies, that when sinter $R$ satisfies production demands, and sinter chemical compositions are not contented other measures except controlling $R$ can not be taken; and that when sinter $R$ is not contented, even if chemical compositions are satisfactory, the measure of controlling $R$ must be taken.

3.1.3 Control centered on basicity

For the sake of realizing the control strategy centered on $R$, avoiding the great fluctuation of production, and reducing the influence of prediction error, the sinter chemical compositions are controlled in accordance with the $R$ real state and its change tendency which is decided by the past, now and future value of $R$.

### 3.2 Sintering process state control centered on permeability

3.2.1 Control strategy centered on permeability

Sintering process state mainly includes thermal state (commonly described by BTP) and permeability state. The bed permeability determines whether the process can go with a swing, and has a hold on the sinter yield and quality. The stand or fall of permeability during sintering affects the stability of BTP. It will be brought forward if the permeability stand, on the contrary, it will be lagged behind. So only with the stabilization and improvement of bed permeability, we can stabilize BTP and sintering process. The control strategy centered on permeability means giving priority to permeability. When the value of this variable is satisfactory, we can stabilize controlling BTP, and when it is abnormal, we have to improve permeability and consider making BTP steady.

3.2.2 Judgement of permeability

There are a number of variables to reflect permeability, such as blast volume through sintering bed ($Q$), vertical sintering speed ($V_{\perp}$), burn through point (BTP), waste gas temperature ($t$) and main negative pressure ($\Delta p$). $Q$ and $t$ are not suitable for they are easy to be disturbed by other factors, like leakage rate, season change, coke level and so on; and BTP is a time-delay variable. So the permeability is judged according to the experience of sintering production by the variables of $V_{\perp}$, $\Delta p$ and the predictive value of BTP.

3.2.3 Prediction of burn through point

On the basis of sintering production experience, BTP is predicted by normal inflexion point of waste gas temperature curve and real BTP value. For example, in No.3 sintering plant of Anshan Iron & Steel Co., the normal inflexion point is situated in the $19^{\#}$ blast box, and its temperature ( $t_{19}$) is about 190 ℃. The matrix of a quadratic form based on BTP and $t_{19}$ to predict BTP was adopted ( Table 1) .

**Table 1** Matrix of a quadratic form for predicting BTP

| | BTP' | BTP | | | | |
|---|---|---|---|---|---|---|
| | | -2 | -1 | 0 | +1 | +2 |
| | -2 | 0 | +1 | +1 | +2 | +2 |
| | -1 | -1 | 0 | +1 | +1 | +2 |
| $t_{19}$ | 0 | -1 | -1 | 0 | +1 | +1 |
| | +1 | -2 | -1 | -1 | 0 | +1 |
| | +2 | -2 | -2 | -1 | -1 | 0 |

## 4 APPLICATION OF SYSTEM

The system which contains nearly 1 000 expert rules in its knowledge base has been employed to the off-line control of sintering process of No.3 sintering plant of Anshan Iron & Steel Co.. The accuracy of its control and guidance is over 80 percent. It successfully steadies sintering chemical composition and makes the qualified sinter and one-grade sinter increased by 1 percent and 3 percent, respectively. It controls BTP, improves bed permeability, stabilizes sintering process and realizes optimum process control. The steady rate of BTP and sintering process are raised by 7 percent and 4 percent. The sinter quantity is increased by 1 percent and sintering consumption is decreased by 1 percent.

## 5 CONCLUSIONS

(1) The control strategies of the sintering chemical composition control centered on basicity and the process state control centered on permeability overcome the difficulty for accurate controlling sintering process, and the predictions of sintering chemical compositions and sintering burn through point offer the solutions to long time delays.

(2) The software of expert system for controlling sintering process, which includes about 1 000 expert rules, has been successfully applied to the off-line control of sintering process in a sintering plant.

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**(Edited by Wu Jiaquan)**