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Intelligent Diagnosis of Coke Oven Heating Production

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Abstract: For reducing the fault ratio of coke oven heating process, based on the analysis of the fault mechanism and case-based reasoning (CBR), an intelligent abnormal work condition diagnosis model is proposed for the coke oven heating process. The probability of the typical fault and their operation guidance with the help of case-based reasoning technology is obtained. The knowledge representation of case and the structure of case-based are studied, and the algorithms of retrieval, learning and reuse are discussed. The proposed abnormal work condition diagnosis system is successfully applied to the coke oven heating process, the fault ratios during production process is decreased, and the proved benefit is achieved. *Copyright © 2012 IFSA.*

Keywords: Case-based reasoning, Intelligent diagnosis, Abnormal work condition, Coke oven heating process.

1. Introduction

Coke oven is an important thermal equipment in the metallurgical industry, disposed by several char rooms and combustion chambers alternatively, coal gas (blast furnace gas, coke oven coal gas) and the atmosphere is mixed, spread and burnt in the combustion chamber, the heat that produces is given to char room through the form transmission of the radiation convection, the coal material is isolated the air and heated (high-temperature dry distillation) and formed the coke in the char room. The coke oven offers the coke for blast furnace, and offer the coal gas to the stove kiln of industry civilly too. Coke is important raw materials of metallurgy and chemical industry trade, quality and output of it concern

stability that follow-up produces directly. If the coke oven breaks down, will influence the coke oven production seriously, will make the working state of the coke oven in the unstable state of even staying cool seriously, cause the coke oven to heat the situation not controllable of the course, so it's essential to carry on fault diagnosis of coke oven heating process.

The artificial intelligent technology has permeated through fault diagnosis field in recent years, for example: intelligent monitoring, intelligent control of automatic processing course, intelligent fault inspection and diagnosis of production process, aircraft intelligent control of flying and landing course and medical course intelligent control [1-5], have made the remarkable result. The research used in this field in the mixing of intelligent technology has been paid close attention to too [6]. Especially case-based reasoning technology is applied to fault diagnosis, a new way is offered to the research of fault diagnosis [7].

Several AFR feedback algorithms have been proposed for controlling AFR. A control strategy incorporating a feedforward controller, inner feedback PI model-based controller, and Smith predictor has recently been proposed [8]. An observer-based fuel injection control algorithm using sliding mode strategy was developed [9]. Choi and Hedrick's algorithm by introducing the second-order sliding mode control with an RBF neural network for gain adjustment was improved. However, these strategies might cause a chattering problem. For improvement, an adaptive neural network strategy was proposed, which employed a radial basis function (RBF) network type, together with the recursive k-means and recursive least-squares algorithms for training the network [10-12]. Parameter estimation for dynamic sliding mode control (DSMC) by using an adaptive radial basis function network strategy was proposed [13]. However these neural network algorithms are too complicated to embed into a microcontroller and the physical meaning of each parameter might not be clear enough. But these control methods do not consider the failure may occur in combustion process, so these control methods cannot be applied here, as the special nature of coke combustion process. Case-based reasoning (CBR) is the process of solving new problems by retrieving the most relevant past problems from an existing knowledge base and adapting them to fit the new situations. Problems are referred as cases and the previously experienced ones are stored in the case base or memory. One of the main advantages of CBR is that it can deal with very complex forms of knowledge. Examples of its applicability are computer aided diagnosis systems for cancer detection, knowledge discovery frameworks for textual case-based reasoning, web-based applications and visual special problem solvers [14].

However, in the coke oven heating process, the effective method that fault diagnosis or prediction of fault trend in order to prevent the emergence of fault is not carried on yet.

Aiming at frequent fault in the coke oven heating process and limitation of tradition intelligent method in fault diagnosis field, abnormal work condition prediction model of coke oven heating process based on case-based reasoning is proposed.

2. Fault Description in Coke Oven Heating Process

According to the structure of the coke oven and characteristic of heating, there are 5 most common production faults in the course of coke oven heating, namely over-heating, premature coke, difficulty in coke pushing, bunch leaks and jam. For a long time, the coke oven operator judges and makes policy to avoid the craft equipment fault according to basis experience knowledge .Once operate the improper, will cause fault emergence, influence the personal security of operator and production process seriously, and influence coke quality. So a set of complete abnormal work condition diagnosis model need to set up to replace patrolling the work of examining of people, improve working efficiency, continuity and stability guaranteeing to be produced.

Coke oven combustion system has complex characteristics of the large time delay and uncertainty of the temperature control, uneven temperature distribution, some faults occur affecting the temperature distribution and the operation of combustion systems production interfered by line information and boundary conditions. Control goal is to maintain the temperature of the combustion chamber central is set temperature, specific targets is that the flue temperature should be maintained at between 1250 ^{0}C~1350 ^{0}C. The distribution of temperature is difficult to accurately model, but the transfer function can be used to describe as following.

$$T(s)=\frac{T_u}{T_{11}s+1}u(s)+\frac{T_v}{T_{11}s+1}v(s)-\frac{T_h}{T_{11}s+1}h(s)-\frac{T_p}{T_{11}s+1}p(s)-\frac{T_F}{T_{11}s+1}F(s) \quad (1)$$

,

where T_{11} represents the main flue temperature time constant; T_u represents the time constant of combustion gas flow; T_v represents the time constant of flue suction; T_h represents the time constant of gas heat value; T_p represents the time constant of the combustion gas pressure; T_F represents the time constant of the failure time in the combustion process; $F(s)$ represents the frequency of failure threatened in the combustion process.

The most fundamental factors those affect the combustion temperature are the combustion flue gas flow and the flue suction. Because the burning conditions (reflected by the gas pressure p), fuel type and composition (reflected by the gas heat value h), and combustion condition (reflected by the combustion process failures F) often change, the air-fuel ratio, the ratio between the combustion gas and combustion air is no longer follow the fixed ratio, has the characteristics of the time-varying and nonlinear. Moreover, some other unpredictable interference factors also affect the stability of temperature during combustion. If the coke oven fails, it will seriously affect the coke oven production, then the work of the coke oven is in a serious state and even unstable, resulting in the situation that the coke oven heating process does not control. Therefore, the fault diagnosis of the coke oven combustion process is essential. According to the structure and characteristics of the coke oven combustion, there are 5 the most common production faults in the coke oven combustion process, namely over-heating, premature coke, difficulty in coke pushing, bunch leaks and jam. For a long time, coke oven operators based primarily on experience and knowledge to judge and decision-making to avoid the process equipment fault may occur. Once the improper operation will result in fault condition, seriously affecting the production process and operator safety and the quality of coke. So it is necessary to establish a comprehensive fault diagnosis system for some phenomena arising in the production process, in which make judgments before failure. The system is used to replace human inspection work, improve work efficiency, and ensure the continuity and stability of production.

3. Intelligent Diagnosis of Abnormal Work Condition by Case-based Reasoning

There is not very good theory model at present to summarize fault information in the coke oven heating process, knowledge of fault diagnosis is not complete or difficult definition, but experienced technologist can rely on abundant experience to take decision of coke oven heating course, judge the present stove condition variation tendency. Case-based reasoning technology can simulate such treatment course, as to traditional expert system, its reasoning ability is strong, knowledge acquisition is easy, it can be used in more complicated system. Case-based reasoning is applied to fault diagnosis, a new way is offered to fault diagnosis. Based on above-mentioned analysis, Case-based reasoning method is proposed to predict potential fault in coke oven heating process and offer operating guidance in order to avoid the emergence of the fault.

3.1. Case Representation and Storage

The case-base is composed of cases that are in pre-defined structure and organization. Case representations the foundation of CBR. The case representation needs to determine the content stored in case, find out a right structure for the content description, and decide how to organize and index for effective retrieving and reusing. The case features are the important factors for constructing case, they define the index information of case, the CBR system carries on retrieving and matching according to the case features. In this paper case can be defined as:

$$Case(F,W) = case((f_1,f_2,f_3,\ldots,f_n),(w_1,w_2,w_3,\ldots,w_n)), \quad (2)$$

where $F=(f_1,f_2,f_3,\ldots,f_n)$, f_i is the descriptive feature, it may be qualitative or quantitative; $W=(w_1,w_2,w_3,\ldots,w_n)$, W_i is the solution of problem.

In this paper, because material composing, different material ratio and Jingtieshan ore grade, which has larger proportion have obvious influence on rate of waste index, these parameters are taken as case features. In this paper, the case representation structure is as followed:

$$Case(F,W) = case((f_1,f_2,f_3,\ldots,f_8),(w_1,w_2,w_3,\ldots,w_5)), \quad (3)$$

where the description feature is $F= (f_1,f_2,f_3,\ldots,f_8)$, f_1 denotes amount of coal injection; f_2 denotes electric current of coke pushing; f_3 denotes coke guide vehicle state; f_4 denotes coke-quenching vehicle state; f_5 denotes heating gas flow; f_6 denotes furnace genitive pressure; f_7 denotes temperature; f_8 denotes coke quality predicted. The solution of the problem is $W=(w_1, w_2, w_3, \ldots, w_5)$, w_1 denotes over-heating; w_2 denotes premature coke; w_3 denotes difficulty in coke pushing; w_4 denotes bunch leaks, and w_5 denotes jam.

3.2 Case Index and Retrieval

CBR is a reasoning mode which obtains the solution of present problem by accessing past similar problem solution in case base. Obviously, how to complete case retrieval effectively and quickly is significant, and it has much influence on efficiency of CBR. So far, there are general several case retrieval strategies such as nearest-neighbor approach, inductive algorithm, Knowledge-guided and module-retrieval .In this paper, the nearest-neighbor approach is adopted, and the similarity between the input case and old cases is calculated, the key of this approach is how to determine the important weight of each features.

The case index is carried on according to problem description features of each case, namely, amount of coal injection, electric current of coke pushing, coke guide vehicle state, coke-quenching vehicle state, heating gas flow, furnace genitive pressure, temperature and coke quality predicted.

After the matching by main index, the similarity is calculated, and all the cases which meet the matching threshold are been searched. The similarity between new case and retrieved eases is given as equation (4):

$$SIM(c_i, c_R)=(wi\times sim(f_i^I, f_i^R))/(w_i), \quad (4)$$

where c_i is the input case; c_R is the retrieved case; SIM (c_i, c_R) is the similarity function; w_i is the significance weight of feature i; f_i^I and f_i^R respectively denotes the value of feature i in input case and retrieved case; $i=8.sim(f_i^I, f_i^R)$ is the similarity function on feature i, and it is defined as followed:

$$sim(f_i^I, f_i^R) = 1 - |(f_i^I, f_i^R)| / max(f_i^I, f_i^R), \quad (5)$$

The threshold of similarity is given by experts, it is an adjustable parameter, if there are many matched cases, the plan maker may enlarge the threshold; If there are little matched cases, the threshold may be reduce, thus ore or several most similar cases to target case can be selected.

3.3. Case Reuse

Once the matched cases are obtained, CBR system will adapt the solutions of selected case according to input case so as to obtain the solution of input case, this process is named as case reuse. It is supposed that k similar cases in case-base are retrieved, then the case adaptation may be carried on according to equation (6):

$$W_{in,i} = \lambda_j W_{j,i}, \quad (6)$$

where λ_j =e $SIM(C_{in},C_{Rj}) / SIM(C_{in},C_{Rj})$, $W_{in,i}$ denotes the i^{th} variable of input case solution, $SIM(C_{in},C_{Rj})$ denotes the similarity between input case and retrieved case j, λ_j denotes the influence degree of retrieved case j to input case.

3.4. Case Learning

The quantity of initial cases in case-base is limited, it is necessary to generate new cases and add them to case-base during plan making process, so the experience is accumulated. Because there are certain rules during plan making, the new plan may be completely same or very similar to the retrieved cases from case base, if all the cases are added to the case-base, the case-base will become lager and larger, thus case learning must be carried on. The main case learning strategies are as followed:

a) When the case matching fails, the plan maker has the right to filter the new case, define and add the case considered to be valuable into the case-base;

b) If the all the similarities between input case and cases in case-base are all less than certain value (for example 0.8), then the case is added to the case base.

4. Industrial Application

In the process of coke oven heating, basic reason influences product and frequent fault is that coke oven production totally depend on experience knowledge of operator to judge stove condition and adopt corresponding operation, not only labor intensity is very great, but also dependability, security and economic validity are all difficult to ensure. Combine the reality of heating course of some coke oven plant, abnormal work condition diagnosis system based on human-computer interaction is developed and applied to production using the method put forward in this paper. The system is applied to some coke ovens No. 10 in Coking and Chemistry Plant, the characteristic weights of 8 variables based on case-based reasoning will be confirmed, described and accords with other relevant knowledge according to the corresponding case, through such operation as the search, matching of the case in the case storehouse of coke oven heating fault, get the diagnosis result in conformity with actual conditions, provide the treatment method. The actual operation result of more than two years indicates, this system can realize correctly the abnormal work condition diagnosis, the accuracy rate of fault diagnosis is up to about 90 %, the operating rate of the equipment improves by 2.5 %, coke quality is improved a lot, stability coefficient of the coke oven and even coefficient are improved.

5. Conclusions

Case-based reasoning technology is proposed to realize intelligent abnormal work condition diagnosis of coke oven heating process. Have avoided setting up the mechanism model difficult and obtaining the defect with difficult knowledge in use of the case-based reasoning technology, prediction in real time of key craft parameter that difficult measurement or lagging behind has offered the characteristic parameter for fault reasoning. Applying to the production practices of coke oven heating, has reduced the trouble incidence by a wide margin, have obviously improve production target, has played an important role in steadily control and stability run of optimization control system of whole course.

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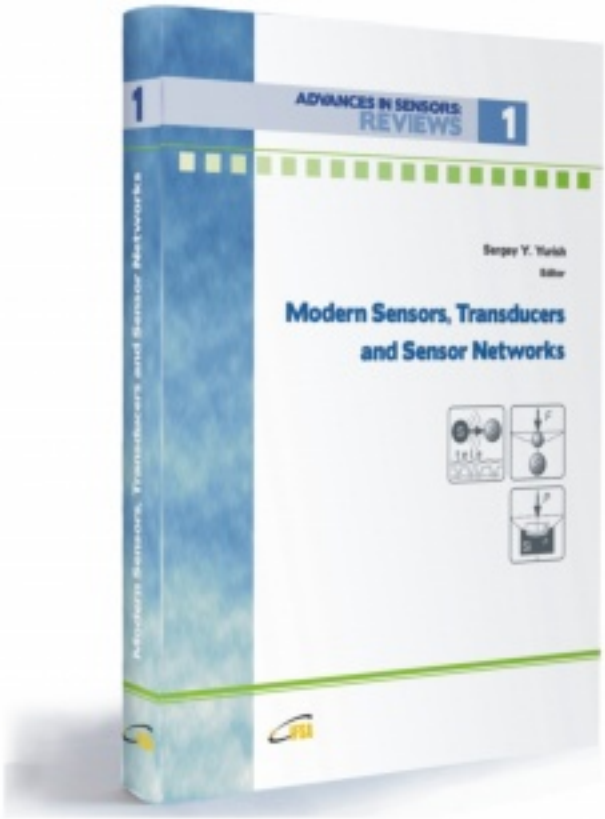

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