CONTROL OF METALLURGICAL UNITS WITH THE HELP OF EXPERT SYSTEMS

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Abstract

Necessity of automation of handling and developing processes of the automated control systems in an metallurgical industry is determined by increasing of labour productivity, enlarging power of the process equipment, increasing a technological level of the fundamental production assets, especially their primarily part, complicating technological processes, increasing the responsibility for abidance of work safety.

Modern technological and socially - economic systems represent difficult soft formalize the systems functioning in conditions of the big uncertainty, incompleteness of knowledge and fuzzy of descriptions both the system, and signals working on it. In due course it became clear, that for management of such systems there is not enough application of classical methods of the theory of control and development of new methods and approaches is necessary. The expert system is a software product filled by experts in which the artificial intellect is used as the typical logic rules. The expert system work is set according the algorithm alike intellective process. The given device is applied for the difficulties of the description of complex processes, absence of any other descriptions. Controlling is carried out on the basis of the obtained knowledge of observable parameters of system by change of control parameters (IVANOV 2007 №1,2; MALJUGIN 2007 №3).

1. DEVELOPMENT OF AN EXPERT CONTROL SYSTEM OF TECHNOLOGICAL PROCESS WITH USE OF FUZZY LOGIC ON THE EXAMPLE OF AUTOMATION OF BLAST PROCESS

1.1 Feature of work of a blast furnace

To the difficult industrial target working in conditions of incompleteness of knowledge and indistinct logic, it is necessary to relate process of melt of iron in a blast furnace - continuously working unit of mine type, current of process in which is based on a countercurrent burden materials and hot gases. An indispensable condition and trouble-free operation of a blast furnace high-efficiency must keep technology of melting particular conditions. However, having 5 - 7 and more entrance and target parameters of action on a drive in a normal mode of functioning are not always obvious and cause the certain difficulties even for very skilled operator. Therefore it is expedient to equip blast furnaces with the expert systems working in a mode of the adviser, assisting to the operator to make in each concrete situation correct decisions.

Now, in Institute of control sciences of the Russian Academia of Sciences (ICS RAS) under a manual d.t.s., prof. Maljugin V.D. is developed a simulator of the master of the blast furnace, having constructed on the basis of behavioral logic model when concepts of a rejection of observable parameters from norm are used. It is supposed, that normal values of observable parameters are determined by an interval \( X + \Delta \) within the limits of which \( X \) accepts value ”=” (equally). Outside this interval intervals of ” more norm ” (>) and “ less norms ” (<) . The detailed of a structure of a blast furnace and the general circuit of blast furnace are submitted in figure 1. Upper a part of the furnace through which make loading burden materials to be charged, name mouth (diameter = 7-8 m.).
The basic volume part of the furnace is the chimney representing the truncated cone. The widest part, belly (d = 12-16 m.), through bosh passes in a well (d = 10-14 m.). The general height of internal space of a blast furnace makes 25-30 m, and in view of that it is a little bit raised on the base and that above mouth is the burden and off gas pipes is situated, the top point of it is above a surface of the ground at a level of 60-70 m. In the top part of a well there is a big number tuyere located in regular intervals on a circle through which is blown air into furnace. In the bottom part of a well there are some drawing off slag and hot iron notches. The internal part of the furnace is lined with refractory bricks for along time campaign. Influence is provided by two technological parameters, as the charge of coke and temperature of mouth (\( t_{K.F.} \)). It considerably reduces time of processing in emergency simulators about several seconds the comparison with some hours in blast furnace. Thus, the qualitative model is in a basis of expert system, all observable which parameters are interpreted in terms of indistinct logic.

1.2 Logic modelling blast furnace process

Feature of developed expert system is application of logic, technological, physical and chemical models of the analytical control (figure 2).

![Figure 1. Distribution of the basic chemical processes along height of a blast furnace](image)

### Figure 1. Distribution of the basic chemical processes along height of a blast furnace

1 - mouth;  
2 - chimney;  
3 - belly;  
4 - bosh;  
5 - tuyeres for blasting;  
6 - slag notch;  
7 - slag;  
8 - hot-iron;  
9 - hot-iron notch.  

**\( t_{K.F.} \) - Temperature of mouth gas, °C**  
**\( t_{u} \) - Temperature of iron on release, °C**  
**\( t_{w} \) - Temperature of slag on release, °C**

**Logical model**  
**Technological model**  
**Physical-chemical model**  
**Analytical model**

![Figure 2. the Circuit of controlling of expert system of a blast furnace.](image)

The principle of modelling is the basic work of logic model with its subsequent influence on technological and physical-chemical models with their mutual influence on 1,2 and 3 channels of influence. A control point of obtaining result (high-quality production) is the model of the analytical control, influence on which appears on 4 and 5 channels of influence.

In logic model of blast furnace process the element of the circuit is understood as the logic table, inputs values of the variables describing the devices with help of which the person can operate process of manufacturing. As the purpose of regulation - deduction of all observable parameters in "norm",...
hence, outputs are the values, observable variables. Inputs and outputs of various elements of the circuit are connected among themselves by conductors (connection) through which values of signals on inputs and outputs of elements are distributed. Logic modelling represents the cyclic process represented in figure 3.

Figure 3. the Basic circuit of logic modeling

The logic model of blast furnace process will consist of 17 elements or logic tables, therefore the turn of messages here is not used. Further is submitted, as an example, the table of logic modelling of intensity downing the burden and temperatures of a well in peripheries of the furnace, together with the module of the converter and the module of quality of blowing in energy (tables 1,2).

The condition of the furnace characterizes the following parameters (observable parameters): a level stockline (Hi), convergence rate of charge (Vi), theoretical temperature of burning of coke (Ti), temperature mouth gas (TK) both the contents of oxygen (O2K) and hydrogen in mouth gas (H2K). Regulation of a course of the furnace can be carried out by the following parameters (managing parameters): the charge (R), temperature (T) and humidity (W) blasting; the charge of fuel additives and oxygen (D); loading of the center and periphery of the furnace (Zi); water under mouth (B). All controlled parameters of blasting and additives will be transformed to models in a universal parameter – quantity of the energy acting in a blast furnace in each step of controlling.

Regulation from above is made with the help of two regulators of loading burden - 1RZ and 2RZ which on an input have signals H and V, and on an output a signal of intensity of charging Z which as well as all other sizes is characterized by three qualitative. Levels: it is less (0), the norm (X), is more (1).

Table 1 - the Module of intensity downing burden and temperatures of a well in periphery of the furnace

<table>
<thead>
<tr>
<th>Inputs</th>
<th>Letters</th>
</tr>
</thead>
<tbody>
<tr>
<td>1Q</td>
<td>0</td>
</tr>
<tr>
<td>1H</td>
<td>X</td>
</tr>
<tr>
<td>1V</td>
<td>X</td>
</tr>
<tr>
<td>1T</td>
<td>X</td>
</tr>
</tbody>
</table>

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<thead>
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<th>Outputs</th>
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</thead>
<tbody>
<tr>
<td>1Q</td>
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</tr>
<tr>
<td>1V</td>
</tr>
<tr>
<td>1T</td>
</tr>
</tbody>
</table>

Table 2 - the Module of the transformer of quality of blasting in energy on periphery

<table>
<thead>
<tr>
<th>Inputs</th>
<th>Letters</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>0</td>
</tr>
<tr>
<td>1R</td>
<td>X</td>
</tr>
<tr>
<td>1Q</td>
<td>X</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1Q</td>
</tr>
</tbody>
</table>
Schematically, the logic model of a blast furnace is shown in figure 4.

![Figure 4. the Circuit of logic model](image)

### 2. APPLICATION OF TECHNOLOGICAL MODEL OF CONTROLLING BY A BLAST FURNACE

Use of the given model represents a set of the formulas explaining and assisting to operator blast furnace process. For example, use of model of expert system in view of productivity of the furnace (1), numbers of output of cast-iron in day (2), etc.:

(1) \( \Pi = \left( K \cdot H_{P/K} \cdot Fe_{III} \right) \cdot 0.95 = \frac{K}{Q_K} \)

i.e.: \( \Pi \) - productivity of the furnace, t/d; \( K \) - quantity of the burnt coke, t/d; \( H_{P/K} \) - burden t/m; \( Fe_{III} \) - quantity melted Fe charge in day; 0.95 - a degree of use of iron charge; \( Q_K \) - the charge of coke, t/t of iron;

(2) \( n_a = \frac{\left( q_H^I + q_H^{III} \right) \cdot 1440}{S_r \cdot h_M \cdot E + \left( q_H^I + q_H^{III} \right) \cdot \tau_a} \)

i.e.: \( n_a \) - number of output of cast-iron in day; \( q_H^I, q_H^{III} \) - volumetric speeds of accumulation of cast-iron and slag, m³/mines; 1440 - quantityof minutes in day; \( h_M \) and \( S_r \) - height and the area of cross-section section of crucible, m, m²; \( E \) - factor of filling of a forge cast-iron and slag, m³/m³; \( \tau_a \) - duration of release of iron, in minutes;

### 3. PHYSICAL-CHEMICAL MODEL OF EXPERT SYSTEM

Also into structure of expert system enters physical-chemical model which includes distribution of chemical elements between cast-iron and slag in a blast furnace. Development and completeness of regenerative processes can be estimated thermodynamic calculations with use of modern theories and models metal and oxide solutions. As an example we shall present distribution of silicon between iron and slag on reaction of interaction silica in slag and carbon in iron:

(3) \( (SiO_2) + 2C = Si + 2CO; \Delta G^0 = 712300 – 370,62 \cdot T \), Joule/moth

With use of the equation of an isotherm of reaction:

(4) \( \Delta G = \Delta G^0 + RT \ln D = -RT \ln \frac{K_p}{D} \)

i.e.: \( K_p = \exp \left( \frac{\Delta G^0}{RT} \right) \) - a constant of balance of reaction

\( \Delta G^0 \) - standard energy Gibson of reaction
\( \Delta G \) - energy Gibson of reaction

\( D = \frac{P CO^{(KOH)} \cdot d Si^{(KOH)}}{d SiO_2^{(KOH)} \cdot d C^{(KOH)}} \) - function of a final condition of iron and slag

\( P_{CO} \) - partial pressure CO in a gas phase
\( d_i^{(KOH)} \) - activity of silicon and carbon in iron and silica in slag.
By given calculations it is possible to accept the optimal temperature 1400°C for redistribution of silicon between iron and slag, as in this case energy Gibson is most approached to balance i.e. \( \Delta G \to 0 \).

4. MODEL OF THE ANALYTICAL CONTROL

The method of the analytical control which represents a final point of check of conformity to quality of production is developed alongside with application in expert system of a blast furnace logic, technological and physical-chemical models. The given model includes the x-ray phase and x-ray spectral analysis. As an example the diagram x-ray phase analysis of studying of structure of iron is shown in figure 5.

![Figure 5. X-ray phase analysis of iron of a blast furnace](image)

According to the chemical analysis sample will consist from карбида Fe with impurity Cr: (FeCr) 3C. A phase: Ferrite + Cementite. According to system ASTM there is some displacement because of the influence Cr on content of Fe. The x-ray phase analysis of iron was carried out on diffractometer Philips PW - 1710. Shooting diffraction pattern was carried out on Cu kα - radiation with use of the nickel filter. Decoding received x-ray of diffraction pattern (Figure 2) was obtained with the help of the automated system of the phase analysis “Rapid”. The conclusion is made on the basis of good coincidence of reflexes experimental diffraction patterns and the tabulated data of card file ASTM (the American society of standards and materials).

Conclusion

We develop expert system (simulator) of the operator of a blast furnace with the combined rudders and malfunctions on the basis of indistinct logic and an artificial intellect with application of technological instructions of operators for prevention of emergencies and improvement of professional skill of the attendants, and also training of students of the senior rates of high schools of technical specialities. Into structure of the given system of a blast furnace enters logic, technological, physical-chemical models x-ray phase and x-ray spectral analysis. Now the simulator is supplemented with balance calculations melting and economy, and also models of ecology and safety of ability to live. Further, we plan to develop the universal expert system (simulator) of high-temperature units on base of already given system of a blast furnace with addition of new models of the tunnel furnace for roasting high-quality refractory and systems of installation on processing slag with the purpose of manufacturing production of iron without waste and producing of building rubble from blast furnace slag.

LITERATURE

2) IVANOV E.B., MALJUGIN V.D. Problem of controlling of units for melt of iron with the help of expert systems // the Collection of theses of the first International conference “ Management of development of