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Application of Artificial Intelligence to Blast Furnace Operating Control System

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Abstract

It is difficult to establish a mathematical furnace model and automatic furnace control because of the difficulty in direct measurement of the inner condition of a blast furnace. To solve this problem, we has developed and actually operated a blast furnace operation control system using artificial intelligence tool to be applied to the blast furnace process computer system. Since this system has a function of automatic heat level control, higher practicality has been proved than the previous guidance-level expert system. This paper introduces an outline of the system and the result of application.

1. Introduction

In the steel industry, many process computer systems have been installed and computerization is highly developed. Recently, expert systems have been introduced in the ironmaking plant to improve automation and efficient operation. Expert systems are most used in a blast furnace of the ironmaking plant. Because, it is difficult to adapt a conventional process control technology in the blast furnace control.

It is difficult to describe theoretically the process condition in the blast furnace since the solid (iron ore and coke), liquid (molten pig iron), and gas react with each other in a complicated manner. Thus, modeling of the process and applying a conventional process control technology is difficult. However, development of AI technology makes process control possible by means of expert systems, in which the experience of the operators is used.

Recently, constructed a blast furnace operation control system by incorporating with a compiler type AI tool called "AIMAX-C". This paper introduces the outline of this process computer system, its configuration and effect of the application of the blast furnace operation control system.

2. Blast furnace computer system

2.1 Total system configuration and outline of functions

Figure 1 shows the hardware configuration of the blast furnace computer system. The computer system is installed in an integrated computer room to ease maintenance, several kilometers distance from the blast furnace facility. Data transfer between the computer and the peripheral system, which are instrumentation controller (DCS), electrical controller (PLC), and the graphic CRT's (man-machine interface) is achieved through the optical data way system. The computer access the process data through the optical data way system. In addition, the processed data are filed for each constant cycle and each event to make a data base which is accessed from each application. The blast furnace operation control system practices an inference based on this data base.

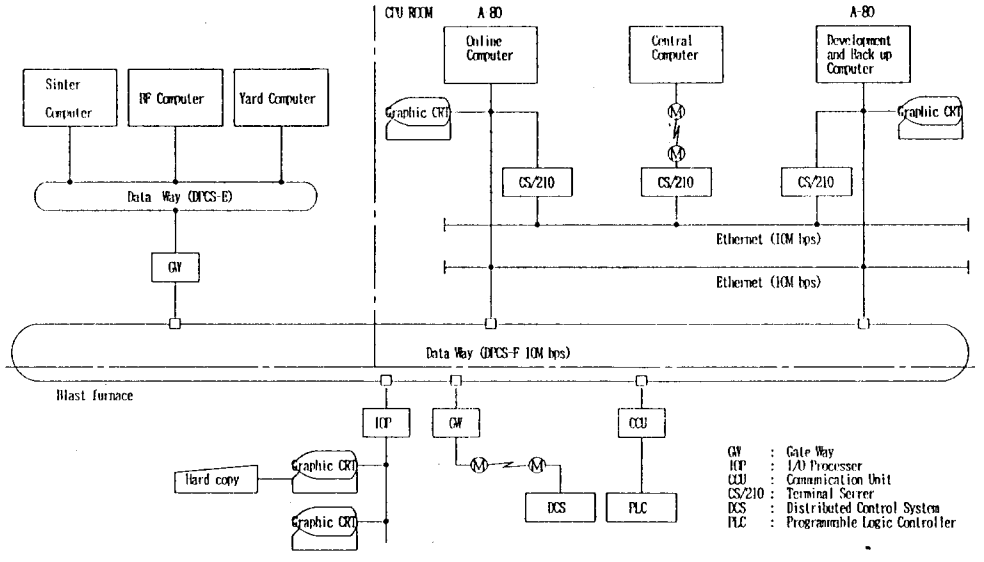

Fig. 1 Configuration of the control system for blast furnace

2.2 Outline of expert systems

There are two methods of constructing expert systems to process computer systems: a method to construct an expert system in the process computer itself and the other method to install a special computer for exclusive use as a back end processor of the process computer.

In the blast furnace expert system has been constructed in the process computer system because with the following reasons.

1) Interface with the processed data is simple.
2) Operational information of the process computer and diagnostic result from the expert system are exhibited on the same CRT.

AIMAX-C of the compiler type expert shell is used as AI tool. AIMAX-C converts inputted knowledge base into source programs of FORTRAN. The execute module of the expert system is produced by compiling this source program. In this conversion, the knowledge base can be converted into not only a main program form but also into a subroutine form. Therefore, combination of an application program and an expert system is easily constructed.

3. Blast furnace operation control system

3.1 Outline of functions

The blast furnace operation control system has the following functions.

1) Diagnoses the condition of the blast furnace based on an amount of process information related to the blast furnace operation.
2) Exhibits the diagnostic result to an operator.
3) Gives guidance for necessary operational action to an operator.

The operators previously diagnosed comprehensively the condition based on information from various sensors and past experiences, since it is impossible to observe the inside of the furnace directly. An expert system can construct an automatic system by means of incorporating such know-how of the operator into process computer. In this process computer system , the diagnosis function is achieved by using such an expert system.

3.1.1 Configuration of the knowledge base

Figure 2 shows the configuration of the knowledge base of the blast furnace operation control system. The phenomena caused in the blast furnace are classified into those which change with a large time constant and those which change unexpectedly. Among the phenomena which change with a large time constant, the thermal condition in the furnace (hereinafter referred as the heat level), the tapping balance, etc. are found. Among the phenomena which change unexpectedly, the rapid change of the blast pressure, etc. is found. To handle these different phenomena, this expert system has two or more knowledge bases as shown below.

1) Knowledge base for stationary diagnosis
   This knowledge base has the knowledge to diagnose the phenomena with a large time constant. This knowledge base is activated periodically to infer and outputs the diagnostic result and the necessary action.

2) Knowledge base for non-stationary diagnosis
   This knowledge base has the knowledge to diagnose unexpected phenomena. This knowledge base is activated when the process data changes due to the occurrence of unexpected phenomena, and it outputs the diagnostic result and the action.

3) Knowledge base for GO-STOP diagnosis
   This knowledge base is equivalent to the GO-STOP system, which is the antecedent of this system, and the knowledge regarding operation in the state of an emergency is described. This knowledge base contribute to cope with rapid change of the blast furnace condition.

3.1.2 Action item

After inference, the diagnostic result and the kind and quantity of the operational action are output by each knowledge bases in the expert system. This system has six operational action items as follows:

1. Blast volume
2. Blast temperature
3. Blast moisture
4. Coke ratio
5. Oxygen addition (quantity of oxygen added to blast air)
6. Blank charge (charging of coke only)

These action items are given to the operator as guidance through the graphic CRT and the voice annunciator. This guidance gives not only the diagnostic result but also reason to obtain the result. This explanation function is achieved by tracing back the rule used to obtain the result. In addition, the actions of blast temperature and blast moisture can be set automatically from the process computer to the instrumentation control system (DCS system).

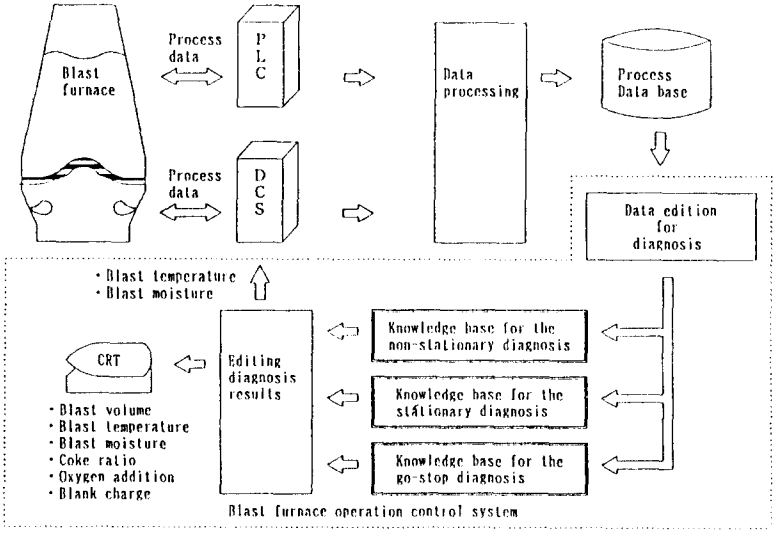

Fig. 2 Composition of the blast furnace operation control system

3.2 Knowledge base for stationary diagnosis

The blast furnace operation control system consists of three knowledge bases and pre- and post-processing as shown in Figure 2. The knowledge base is described in AIMAX-C. The pre- and post-processing are described as usual programs in FORTRAN-77. The knowledge base for stationary diagnosis is introduced here among the three knowledge bases.

3.2.1 Configuration of the knowledge base for stationary diagnosis

Figure 3 shows the configuration of the knowledge base for stationary diagnosis. The knowledge is described by using the production rule and is classified into some rule groups with each function. The main part of knowledge base consists of the following three rule groups.

1) Individual rule group
2) Best action rule group
3) Forward action rule group

The individual rule group has 23 kinds of rule groups concerning each individual phenomenon to be diagnosed. Further, these rule groups are divided into three rule groups: situation analysis, phenomenon recognition, and action determination to reflect the operator's idea on the inference. The diagnostic result and the action instruction as a guidance to the operator are determined through the final diagnosis which consists of the best action rule group and the forward action rule group, based on some diagnostic results derived from each individual rule group.

A "meta rule" is a rule group which activates the "main rule" by judging the operation level of the blast furnace (in operation or blowing down). A main rule is a rule which activates the necessary rule module of the knowledge base for stationary diagnosis at the predetermined inference timing. These rule modules are categorized as those which operated once 5 minutes, 15 minutes or a day basis. The "filing rule" edits the judged result in order to output to the operators.

Transmissions of the intermediate inference results between each rule group are made by using the knowledge frame. In addition, the global variable, which is specific to AIMAX-C, is used for

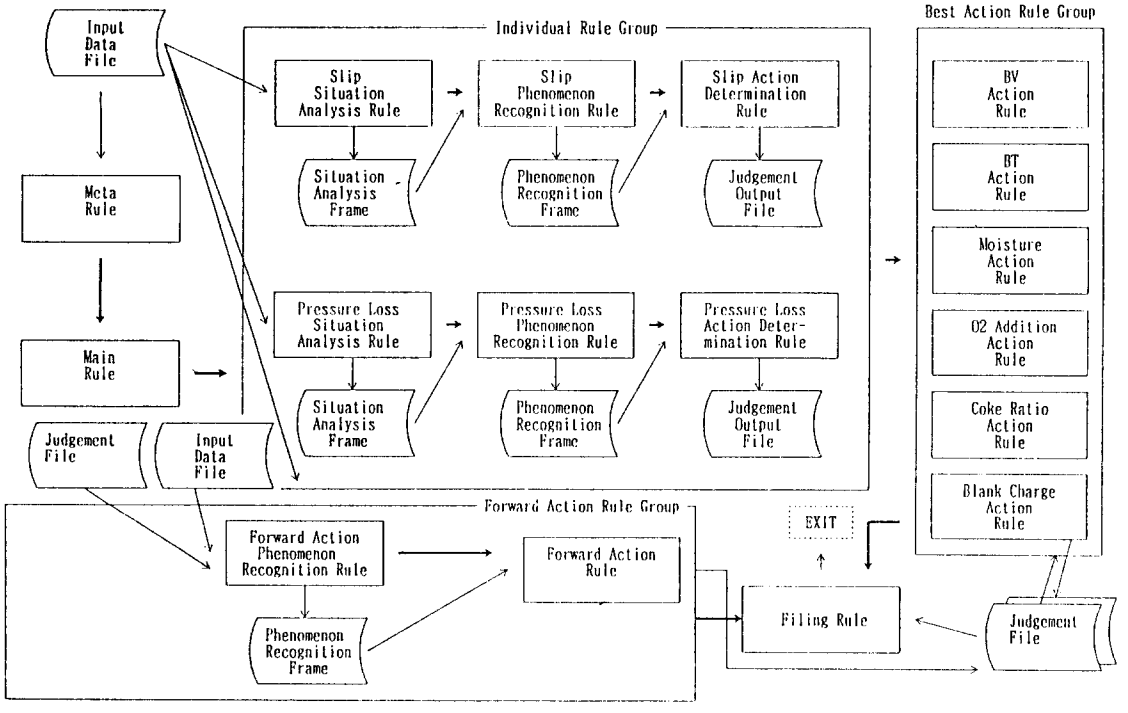

Fig. 3 Configuration of the rule groups

the transmissions of the Input/Output data between the knowledge base and its pre- and post-procedure processing. This global variable ease to refer the data of process files used in procedure processing. Some parts of the knowledge of the blast furnace operation control system can be described in a mathematical expression more easily than in some simple production rules. In such cases, the mathematical expression base which is specific to AIMAX-C is utilized in coordination with these rules. Table 1 shows the scale of the knowledge base for stationary diagnosis.

Table 1 Scale of the knowledge base

Name	Number of production rules	Number of knowledge frames	Execution timming
Knowledge base for the stationary diagnosis	508	50	Every 5 min. 15 min. and 1 day (different from rule groups)
Knowledge base for the non stationary diagnosis	50	5	Exectuted by events
Knowledge base for the go-stop diagnosis	37	1	Every 15 min

3.2.2 Operator interface

In expert systems, the interface with operators is very important. Thus, some special screen of exclusive use is made in the system to offer easily comprehensible information to the operators. Examples of the screens are shown in Figures 4 and 5.

Figure 4 shows a screen where the diagnostic result and action instruction are exhibited to the operator. This screen can exhibit not only the result but also the diagnostic reason. Figure 5 shows a screen to be output when the changed state of the heat level is diagnosed. This screen gives the operator the trend graph of the data related to the heat level. The operator can judge whether the diagnostic result given by the system is acceptable or not since the operator can infer the state of the heat level by himself referring to the trend graph on the screen. Some of these trend display screens exist for each phenomenon to be diagnosed. In this system, all data used for the diagnosis are automatically input. Therefore, the operator need not input the data manually. What is requested for the operator is only to operate actual action quantity according to the diagnostic result and action instruction given by the system.

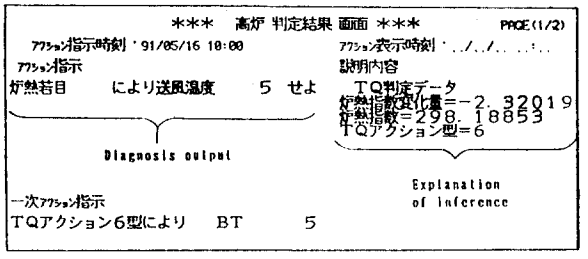

Fig. 4 An example of diagnosis output and explanation of inference flow from the blast furnace expert sistem

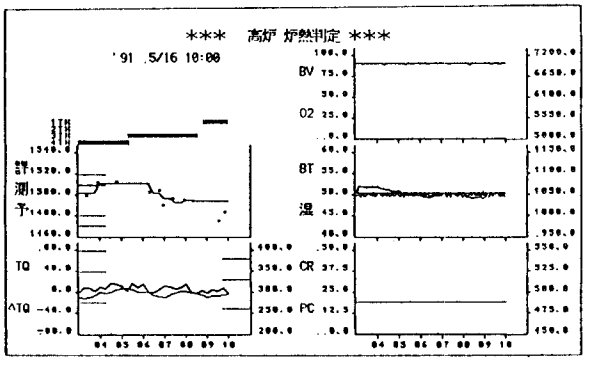

Fig. 5 Trend graph of the heat level

4. Application results

The blast furnace operation control system is a diagnostic system in a guidance type. The operator judges whether the action instruction can be executed after examining the output from this system. Therefore, some times, the operator doesn't execute the action instructed by the system, and this system's function cannot be used sufficiently even if the coming-true rate of the diagnosis is improved after tuning of the system. Then, this system automatically sets up the target value of the blast temperature in DCS output from the system , when the change of the heat level is diagnosed in the stationary operation. The automatic control of the closed loop of the heat level is achieved by this processing. The results of the control are shown in Figure 6.

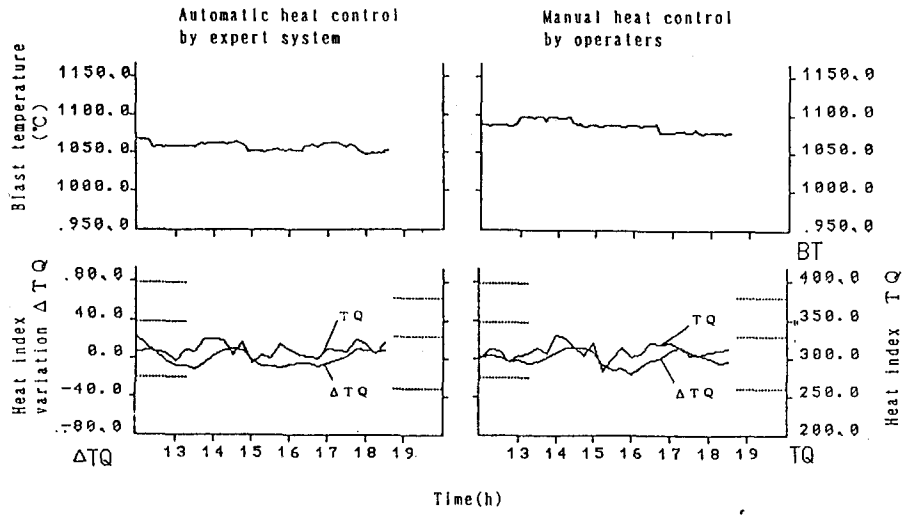

Fig. 6 Results of the automatic blast furnace heat control

This figure shows the change of TQ (heat index) which is the index of the heat level and the change of △TQ (heat index variation) when the blast temperature (BT) is controlled. Both TQ & △TQ changes are controlled at a favorably comparative level from the judgment of the operator. From these results, it is understood that the automatic heat level control functions sufficiently. This automatic heat level control gives the more practical use to the blast furnace operation control system than in the case of the guidance level.

This expert system is formed in execution modules, it works in the same environment with the usual processing procedure, and its execution speed is high. For processing the total knowledge of this system, the execution time is about six seconds. This system can be evaluated to have sufficient performance as an on-line expert system of the diagnosis and control type for blast furnace operation.

5. Conclusions

The configuration of the knowledge processing and effect of the application were described with the blast furnace operation control system of the blast furnace process computer system. In addition to the system introduced in this paper, this computer has many systems to which AI technology such as expert systems and fuzzy control systems. These systems are constructed by using AIMAX-C and contribute to the blast furnace operation. AI technology is coming to be essential and indispensable in the operation of the blast furnace. The applications of AI technology for automation will be extended in future.