Development of a Channeling Prediction System for a Blast Furnace

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An uneven gas distribution through the burden layers inside a blast furnace (BF) results in abnormal gas resistance or pressure changes. Rapid variations in the abnormal gas resistance will lead to the occurrence of channeling. A visualization technology mainly made of pressure distribution was developed to predict BF channeling phenomena in this study. The real-time data of BF shaft pressure was used to create a 3D visual model by neural network algorithms and 3D real-time BF pressure changes were observed. The root mean square deviation (RMSD) of the BF shaft pressure was used as an index to set up the predicting criteria of channeling occurrence with the opening of BF Annular Gap Element (AGE), and a predicting system based on the criteria was built. The two criteria for the channeling alarm are the RMSD of the BF shaft pressure (> 0.15 kg/cm2) at the seventh level (L7), and the AGE opening being greater than 60%. This system has been installed in China Steel (CSC) No. 2 BF, and the test results showed that a prediction can be obtained 10 to 15 minutes ahead of channeling allowing sufficient time for the operator to adjust the BF operation in order to avoid the occurrence of channeling.

Keywords: Channeling prediction, Blast furnace, Visualization

1. INTRODUCTION

Channeling often occurs in the blast furnace (BF) because of various causes such as excessive fine charging, improper burden distribution and high level of liquid iron-slag in hearth. The channeling leads to an increase of the heat load at the BF wall, which results in an unstable BF operation and reduced production. If the channeling can be predicted effectively, the BF heat load could be opportunely reduced by improving the quality of the raw materials or by adjusting the BF operation. In previous technical literature, POSCO (1) developed a knowledge-based system to forecast channeling phenomena inside a blast furnace with the information of cohesive zone shape change and drainage delay. The POSCO system built to detect channeling consisted of two groups: channeling conditions (gas permeability, liquid level in hearth and skin flow temperature etc.); and channeling characteristics (top pressure deviation, lower pressure changes, upper pressure changes, above burden probe data variation, gas utilization ratio change and top gas temperature etc.). About 60% of the prediction percentages were obtained based on the off-line simulations. NKK(2) investigated the BF channeling mechanism by installing an acoustic emission sensor. The NKK study found that channeling was mainly caused by burden distribution changes which affected the falling of materials from the upper layer leading to the growth of a highly porous region in the lower shaft, and increasing the non-uniform gas flow velocity. In addition, the NKK study showed the phenomena of decreasing blow pressure, shaft pressure and gas utilization ratio, and increasing skin flow temperature from the sensors installed in BF. The abnormal trend of isobar distribution in the low permeable zone occurred at the bottom of the BF (due to high resistance), and gradually extended upward.

The visualization of the operating data at CSC was similar to the visual application at NSC(3). NSC developed a 2D system, where the data could be presented at various times at different elevations (each elevation of 10 to 11 temperature and four pressure measurement points) in four different directions (East, South, West and North). Generally, the previously-known channeling prediction technologies still had the disadvantages of using excessive parameters, a lack of accuracy, and relying on human judgment. In the past, it was determined whether there was channeling by observing this 2D visual data obtained from the BF, but there was no tool to predict channeling specifically, thus resulting in frequent channeling inside a BF. Due to the consecutive severe heat load of No. 2 BF from October 2009, the aim of this study was mainly to develop a channeling prediction system for No. 2 BF.

2. VISUAL DEVELOPMENT OF BF SHAFT TEMPERATURE AND PRESSURE

The visual development process was carried out for the CSC No. 2 BF as shown in Fig.1. The process started with an overall mapping of the measuring points for temperature and pressure from the original BF contour into the model in this study. Then the mapping was developed into a BF visual model from the general regression neural network (GRNN) by collecting the data measured from sensors embedded in the BF wall. Finally the modeling data obtained was used to create 3D and color images by interpolation. GRNN is a one-pass learning algorithm with a highly parallel structure. Even with sparse data in a multidimensional measurement space, the algorithm provides smooth transitions from one observed value to another. The algorithmic form can be used for any regression problem in which an assumption of linearity is not justified. The parallel network form could find use in applications such as learning the dynamics of a plant model for prediction or control.

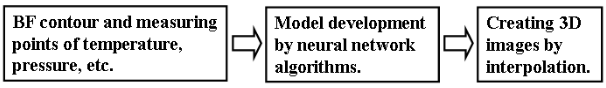


Fig.1. Flow chart of BF visualization development.

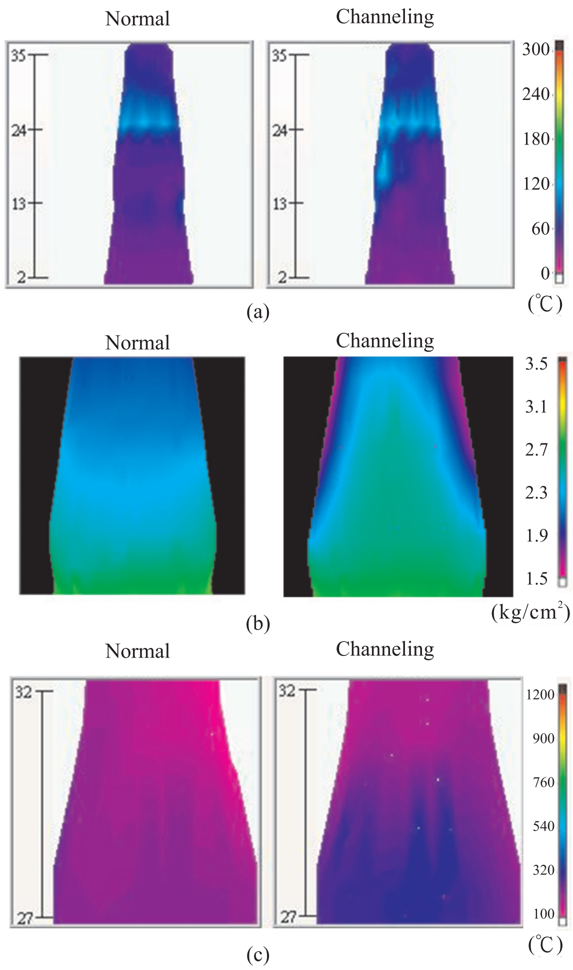


Fig.2. Diagram of visual model for the distribution of : (a) shaft temperature; (b) shaft pressure; and (c) skin flow temperature.

Figure 2 illustrates the pressure distribution under the conditions of normal BF operation and BF channeling. It shows that stable pressure changes always exists in normal BF operation, Conversely, the BF pressure profile surged from bosh to top when channeling occurred.

It was found from Fig.2 that the No. 2 BF shaft pressure change profiles were similar to BF channeling behavior, and it was also known that shaft pressure changes can be a key factor to predict channeling phenomena inside a blast furnace, induced from the analysis results of visual temperature, pressure and skin flow temperature. Therefore, this study focused on the changes in the shaft pressure to develop a predicting system for BF channeling.

3.DEVELOPMENT OF BF CHANNELING PREDICTION SYSTEM

3.1. Prediction criteria of BF channeling

The data on pressure variation at the No. 2 BF over a period of five months from June to October 2010, was observed in this study to specifically quantify pressure distribution in order to set up the prediction criteria for BF channeling. The statistical results indicated that most of the pressure changes were very small except when the abnormal furnace conditions such as channeling occurred. Therefore the abnormal critical value of shaft pressure changes was estimated in this study. The root mean square deviation (RMSD), statistically known as the standard error, was defined as an index derived from the following Equation for the abnormal shaft pressure changes in a vertical direction :

$$\mathrm{RMSD} = \left[\sum_{i=1}^{N} (x_{i+1} - x_i)^2 / N \right]^{1/2}$$

where, x: vertical pressure; and N: the level of pressure changes (> 0.15 kg/cm^2).

The pressure changes in the above equation were determined by observing the pressure variations over the above-mentioned period. That is, the pressure changes were less than 0.05 kg/cm^2 for no BF channeling; however, all pressure changes larger than 0.15 kg/cm^2 signalled BF channeling. In No. 2 BF, there are 32 sensors distributed in four directions; in other words, four sensors are installed at each of eight levels, so N is defined as the pressure change at Level 1 to Level 8. The real-time data for June 2010 was put into Equation to calculate RMSD, and the count of RMSD above the sixth level (L6) was plotted versus the date while comparing with the count of burden slip and time of channeling occurrence, as shown in Fig.3. Figure 3 significantly shows that the count of RMSD plotted was positively correlated with the count of burden slip. Furthermore, the count of burden slip was exactly in accordance with the time of channeling occurrence, and this result was also consistent with the data presented in the literature[3]. Therefore, the RMSD in the vertical direction was proved to be a suitable index for describing the occurrence of BF channeling.

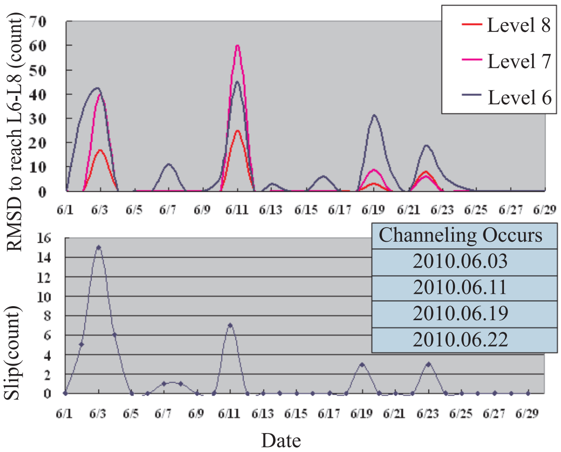


Fig.3. Count of RMSD above L6 versus date while comparing with the count of burden slip and time of channeling occurrence.

In No. 2 BF, BF channeling occurrence can be recorded when a rapidly surging gas flow forced the Annular Gap Element (AGE, the control valve opening in the top of BF) valves to open up to 100%. Therefore, AGE opening was introduced into this study to integrate with the real-time visual data for the position of abnormal shaft pressure changes and RMSD as a trend plot. Figures 4 and 5 are the trend comparisons for detecting channeling occurrence and normal BF conditions, respectively.

The results showed that the trends of RMSD and abnormal shaft pressure changes intensify and reach above L7 when channeling occurs and AGE opening is 100%. Therefore, abnormal shaft pressure changes found in higher elevations and intensive RMSD trends

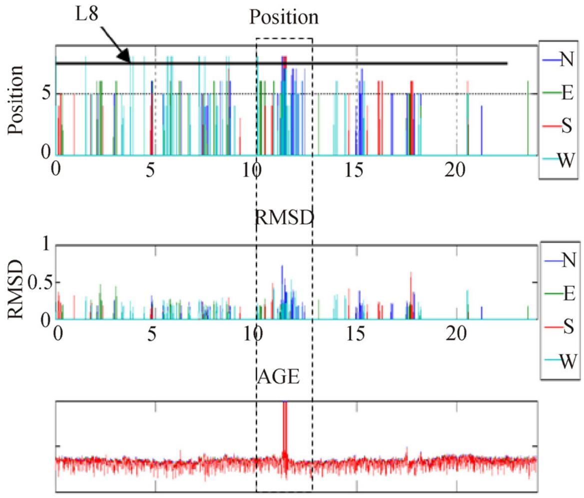


Fig.4. Trends for detecting BF channeling (with channeling occurrence).

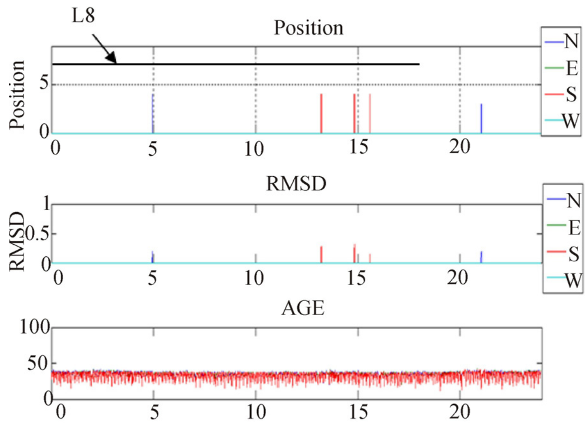


Fig.5. Trends for detecting BF channeling (without channeling occurrence).

are both precursors for the occurrence of BF channeling. In addition, from the discussions with experienced BF specialists, the criteria of 60% AGE opening was determined as a warning of possible channeling. Based on the above analysis, the identification process of BF channeling was set up in this study as shown in Fig.6. The warning signal was given in this system when both RMSD reaches to L7 and the AGE opening is 60%, and the system alarm is given to BF person when both of the RMSD reaches to L8 and the AGE opening is 60%.

3.2. BF channeling prediction system

LabVIEW programming was used as the tool to develop this system, and the 3D model was created by using about 100,000 points based on corresponding measuring points obtained from the BF. The main function of this system includes “Live View”, “Trend View”, “Alarm Table” and “Setup”. Giving “Live

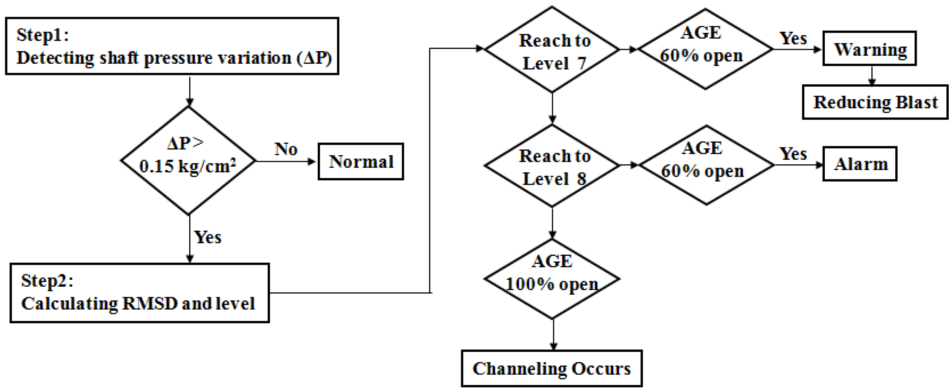


Fig.6. Identification process of BF channeling.

View" as an example, the real-time visualization of BF shaft pressure (renewed every 10 seconds) in four directions, the AGE opening, the elevation and direction of abnormal shaft pressure changes, are all presented on the screen. The different colors on the screen are adopted to represent the severity of the incident: Gray, Dark Gray, and Black for normal, warning, and danger respectively. When the AGE opening is greater than 60%, and shaft pressure changes are greater than 0.15kg/cm^2, the colors of the functional items on the screen is Black (danger). As demonstrated in Figs.7 and 8, the "Live View" presents Gray for normal BF conditions and Black for channeling occurrence, respectively.

3.3 Application

The data of August 11, 2010 is used in this system to demonstrate the prediction of BF channeling as shown in Fig.9. Figure 9 shows that the system will simultaneously output a warning message to the program-controlled computer to alert BF operating staff when warning lights.

Based on the "Setup" for the channeling alarm, the warning appears 10 to 15 minutes ahead of channeling allowing sufficient time for the operators to adjust the operation and thus avoid the occurrence of channeling.

4. CONCLUSIONS

This study developed the visualization technology to predict BF channeling, and the key technologies and application are described as follows:

(1) 3D real-time BF pressure changes were observed from a visual model created by general regression neural network (GRNN) algorithms.

(2) The criteria for the channeling alarm were mainly the RMSD of BF shaft pressure (> 0.15 kg/cm^2) at L7 (the seventh level), and the AGE opening greater than 60%.

(3) A predicting system based on the above criteria has been installed at CSC No. 2 BF, and the test results showed that a warning can be obtained 10 to 15 minutes ahead of channeling enabling the adjustment of the BF operation to avoid the occurrence of channeling.

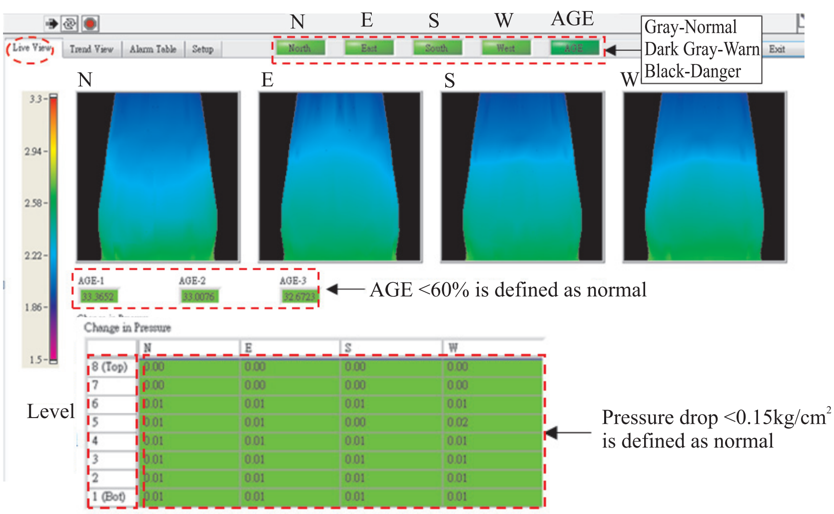


Fig.7. "Live View" for normal BF conditions in this system.

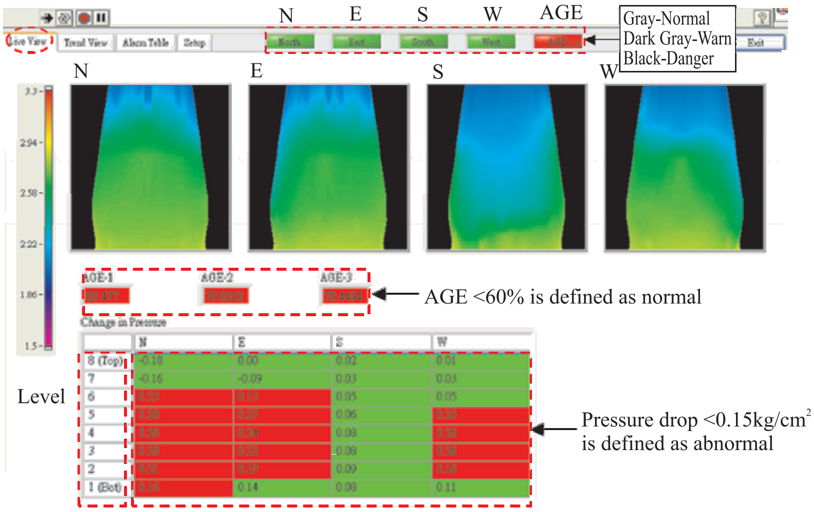
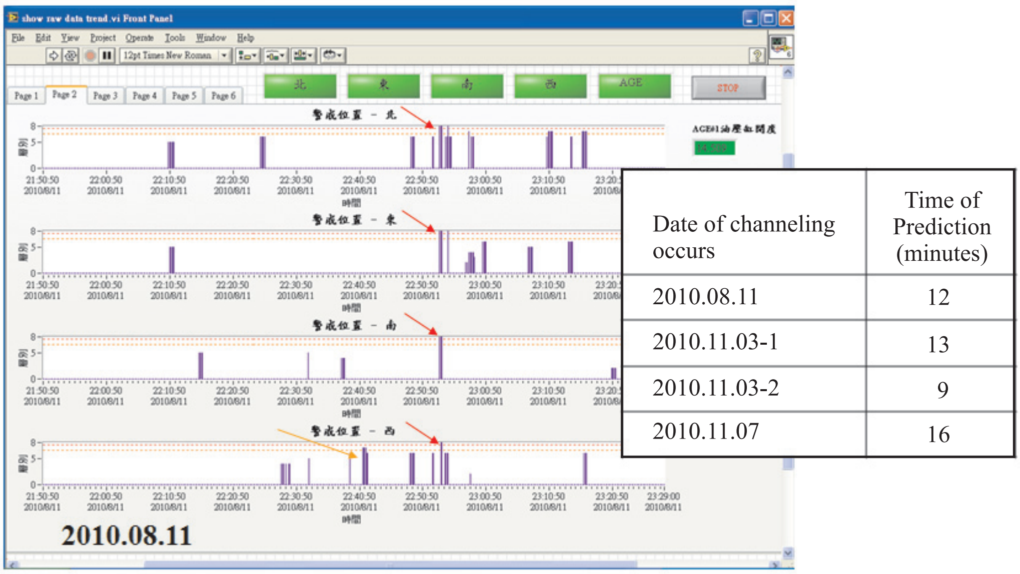


Fig.8. "Live View" for channeling occurrence in this system.



Date of channeling occurs	Time of Prediction (minutes)
2010.08.11	12
2010.11.03-1	13
2010.11.03-2	9
2010.11.07	16

Fig.9. Application of this system in CSC No.2 BF.

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