Temperature Field Acquisition And Data Analysis Of Coke Oven

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Abstract. In coking process of the coke oven, in order to realize the accurate detection of the temperature field data of the coke oven, this paper designs a high precision timing automatic inspection device. It uses a infrared pyrometer to quickly obtain the radial temperature profile of the flue, then based on it, it can get accurate flue temperature through analyzing. The temperature distribution of coke oven depends entirely on the results of the representative flue. The comparison between the temperature measured by the system and the temperature measured by people shows that the system is stable and reliable, it can accurately obtain the temperature of representative flue, then analyze the temperature field of the whole coke oven which taken as an important basis for adjusting the coke oven process parameters and ensuring the quality of coke.

1. Introduction

Coking is the pyrolysis of coal, that is to say, after putting the mixed coal that reach the required into the coking chamber at normal temperature, the coal is heated by the heat flow from the furnace wall and furnace bottom under the condition of isolating air. From the wall of the coking chamber to the center of the coking chamber, the coal charge is finally transformed into coke after a series of processes such as drying, preheating, and decomposition layer by layer. With the development of BF technology, the requirements for coke quality have gradually increased. Coking temperature is an important factor affecting the quality of coke. The highest temperature and heating rate of coke oven directly affects the briquetting rate and strength of coke [1], [2], [3], [4]. In order to control heating in time and improve the uniformity of coke heating, it is required to track the temperature change of coke oven and detect the temperature distribution of coke oven in real time [5]. Therefore, the
detection of combustion chamber temperature has been an important daily work of coke oven production.

The traditional manual measurement method is that workers use a hand-held infrared radiation thermometers to measure the temperature of the coke oven at the top of the furnace. Because of the high ambient temperature, great amount of dust, arduous measurement task and high measurement frequency, the integrity of measured data is easy to be affected, and the measuring accuracy depends on manual experience, which often leads to inaccurate measurement results. In view of this phenomenon, a variety of vertical flue temperature measurement methods have been designed at home and abroad. Such as measuring temperature continuously with infrared pyrometer at the top of the furnace, measuring the temperature of the furnace wall with a coke rod, measuring temperature of the red coke, Measuring the temperature of waste gas and so on [6]. Mingdong Zheng used thermocouples to measure the temperature at the top of the regenerator and established a mathematical model to indirectly obtain the the temperature of flue [7]. This indirect measurement method has many influencing factors and its accuracy is often not high. Yongjin Xu designed an on-line continuous temperature measurement system for vertical flue, which installed a pyrometer on the furnace cover of the flue and laid gas pipe and transmission line, so that it can realize real-time on-line temperature acquisition [8]. However, due to complicated process and high cost, the system can only be installed on a few representative flues near the rail, so it unable to obtain all the representative flues temperature.

In view of the above background and reasons, this paper designed a high precision timing automatic inspection device. The inspection robot with a infrared pyrometer can automatically obtain the radial temperature profile of the flue at a fixed time, and get the accurate flue temperature through analyzing. The host computer analyzes the temperature data and gives the temperature distribution of the coke oven. Through the comparison and analysis of temperature measured by this device and manual temperature measurement data, the feasibility of the device is verified.

2. Structure of the inspection system

The whole temperature measuring system is mainly composed of host computer, server, inspection robot and wireless communication network. Inspection robot communicates with server by wireless module. Temperature measurement control command is sent by host computer. After receiving the instruction, inspection robot starts to obtain the temperature. Temperature data is uploaded to server through wireless module. The server processes and saves the data, then the processing results are displayed by host computer.
Figure 1. Structure of inspection robot.
As shown in figure 1, inspection robot is composed of microprocessor module, power module, drive module, position module, temperature sample module, communication module, battery management module, power supply module and signal input module. The core chip is STM32F4 series ARM architecture chip, and the embedded software adopts FreeRTOS operating system. The robot with a pyrometer in the middle runs on a fixed rail to obtain the temperature of the flue. Temperature data is transmitted to server through a wireless device. There is a radio frequency card device pre-marked with the flue number on the guide rail to ensure that the collected temperature corresponds to the actual flue. The inspection robot is small in size and can freely pass through the bottom of the coal charging car to ensure that the temperature collection is not affected by coal filling and pushing.

The host computer takes the Visual Studio as the software development tool, and uses the pull menu and the visual icon dual drive to realize the system function. The functional modules are shown in figure 2. It is mainly used to control the inspection robot to collect temperature regularly, monitor the running status of the robot, and receive the temperature data uploaded by the robot and display the temperature distribution of the coke oven.

Figure 2. Host computer functional framework

3. Collection and analysis of the temperature data of the flue

3.1. Collection of flue temperature
Generally, 8# and 25# flue are selected as representative flue. Taking 55 hole coke oven as an example, there are 56 representative flues need to be measured on each side of the coke oven. The coking chamber phase is changed every 30 minutes, and the time interval between 1# furnace and 2# furnace is 10 minutes. After 5 minutes of phase change, the inspection robot starts to obtain the temperature of the flue with downdraft. When the inspection robot passes through the flue, the flue cover is opened by the automatic cover opening mechanism, then the pyrometer continuously irradiates the bottom of the flue to obtain the flue temperature. After the inspection robot passes through the flue, the flue cover will close automatically, and the robot will speed up to the next flue which needs temperature collection. After inspecting all the flue, the robot returns to the Charging position and waits for the inspection of 2# furnace.

3.2. Analysis of radial flue temperature
The inner diameter of flue is 12cm. The inspection robot collects temperature data every 6mm on average. The number of radial temperature is affected by many factors such as the degree of inclination of the track, the degree of inclination of the pyrometer, the ambient temperature, the speed
of the robot and the concentration of smoke. Considering that even though the temperature measurement data and temperature distribution of each flue are different, it has certain regularity, so it is necessary to analyze several typical temperature distributions.

When the inspection robot passes through the flue, the temperature value (T) obtained at different positions (Z) from the positioning radio frequency card is shown in figure 3(The distance between the center of the radio frequency card and the center of the flue is 230mm). Ideally, the temperature in the center of the flue is the highest, and it gradually decreases toward the surroundings. As the robot slowly passes through the flue, the measured temperature distribution is shown in figure 3(a), which contains the rising and falling processes, and temperature stationary region is obvious. When the pyrometer is tilted relative to the flue, it will change the detection area, causing the temperature distribution to shift. When the pyrometer is biased to the side of the coal tower, the temperature distribution of the flue measured by the inspection robot in the 1# furnace is shown in figure 3(b). It can be seen from the figure that the rising process of temperature distribution is longer, but there is no falling process. It also has a obvious temperature stationary region. When the pyrometer is biased to the side of the platform of coke oven, the temperature distribution of the flue measured by the inspection robot in the 1# furnace is shown in figure 3(c). It can be seen from the figure that the falling process of temperature distribution is longer, but there is no rising process. The temperature stationary region is also obvious. The influence of smoke on temperature measurement is random, as shown in figure 3(d), light smoke has no effect on temperature measurement, thick smoke will cause the measured temperature to be low, but it does not exist for a long time. Therefore, we can still find a temperature stationary region from the temperature distribution.

![Figure 3. Radial temperature distribution of the flue](image_url)

In general, no matter how the temperature distribution changes, it will have a temperature stationary
region, which can truly reflect the temperature of the flue. Therefore, it is extremely important to find temperature stationary region from the temperature distribution. In this paper, the difference method is used to select the region of temperature difference less than 10. In this region, the temperature fluctuation is small and its reliability is high. Finally, the median of the selected temperature range is taken as the actual temperature of the flue. Figure 4 shows the selected temperature stationary region, and calculates that the flue temperature is 1288°C, 1278°C, 1279°C, 1286°C, the error with the established coke side standard temperature of 1275°C is within ±20°C, which meets the production requirements.

![Figure 4. Screening results of radial temperature distribution of the flue.](image)

![Figure 5. Lateral temperature distribution.](image)

3.3. Distribution and analysis of temperature field
3.3.1. Lateral temperature. Lateral temperature is an important test item to test the horizontal temperature uniformity and reasonable distribution of the combustion chamber [9]. As the coking chamber gradually widens from the machine side to the coke side, the amount of coal is also gradually increased, the required heat increases as well. In order to make the coke cake mature uniformly in the coking chamber at the same time, the flue temperature must be increased uniformly from the machine side to the coke side. After obtaining the temperature, the inspection robot analyzes the temperature difference between machine side and coke side to characterize the lateral temperature. Figure 5 shows the temperature (T) as well as the temperature difference (ΔT) between machine side and coke side of 1# furnace. It can be seen that the temperature difference between machine side and coke side fluctuates around the average value, and the error is within the specified ±20°C, indicating that the lateral temperature is uniform and stable, which meets the production requirements.

3.3.2. Average coefficients and stability coefficients. The evaluation of coke oven temperature usually adopts average coefficient \( K_e \) and stability coefficient \( K_s \).

\[
K_e = \frac{Q}{N} \quad (1)
\]
\[
K_s = \frac{Q_a}{N} \quad (2)
\]

In equation (1), \( Q \) is the number of representative flue in which the difference that less than 20°C between the actual temperature in a single temperature measurement and the standard temperature. \( N \) is the number of representative flues on the coke side or machine side of the whole furnace, and there are 56 representative flues on the machine side and the coke side respectively. It can be seen from figure 6(a) that \( Q \) is 49 and \( K_e \) is calculated to be 0.87. The maximum value of \( K_e \) is 1. The closer \( K_e \) is to 1, the more uniform the overall temperature distribution of the coke oven at this moment.

\[
K_s = \frac{Q_a}{N} \quad (2)
\]

In equation (2), \( Q_a \) is the number of representative flue in which the difference that less than 20°C between the average diurnal temperature and the standard temperature. \( N \) is the number of representative flues on the coke side or machine side of the whole furnace. It can be seen from figure 6(b) that \( Q_a \) is 56 and \( K_s \) is calculated to be 1. The maximum value of \( K_s \) is 1. The closer \( K_s \) is to 1, the more stable the daily average temperature of the coke oven.

**Figure 6.** Temperature distribution

In equation (2), \( Q_a \) is the number of representative flue in which the difference that less than 20°C between the average diurnal temperature and the standard temperature. \( N \) is the number of representative flues on the coke side or machine side of the whole furnace. It can be seen from figure 6(b) that \( Q_a \) is 56 and \( K_s \) is calculated to be 1. The maximum value of \( K_s \) is 1. The closer \( K_s \) is to 1, the more stable the daily average temperature of the coke oven.
3.3.3. **Radial temperature.** The radial temperature represents the average temperature level of the whole furnace, and it is one of the main parameters that directly affect the coking rate and coke maturation time [10]. In actual production, the radial temperature is usually taken as the main index of coke oven gas regulation. Figure 7 shows the change of the radial temperature in one day. As the average value of the coke oven temperature, the radial temperature will fluctuate up and down due to the temperature change of each flue, but the overall temperature is relatively stable, indicating that the overall control of the coke oven is good.

![Figure 7. Radial temperature in one day](image)

4. **System testing and verification**

The main interface of the host computer is shown in figure 8, which displays the information of inspection robot, including the current position of robot, card number, hole number, speed, battery level, fault indicator, direction, working mode and temperature data curve collected by the robot. The host computer can also send control commands to the robot to control the robot to move forward, backward, return to the charging position, obtain the flue temperature and so on.
**Figure 8.** Host computer temperature analysis interface.

The temperature analysis interface of the host computer is shown in figure 9. It integrates the temperature measurement data fixed 6 times a day, then analyzes and calculates the single average temperature, the upper limit number, the lower limit number, the average coefficient and the stability coefficient and the daily average temperature. It also can display the temperature distribution of the coke oven.

**Figure 9.** Host computer main interface.

It can be seen from table 1 that the error between the radial temperature of coke oven and the temperature required by the actual factory is not more than ±20℃, which meeting the production requirements of the factory. Because of the influence of industrial production, such as pushing and
coal filling, the temperature of different flues varies greatly. In fact, because the factory uses the 5-2 sequence method to push coke, the temperature of the coke oven will be in a wavy Distribution, and the temperature of the flue with a sequence number difference of 5 is similar.

Table 1. Flue temperature.

| 1# machine side | 1# coke side | 2# machine side | 2# coke side |
|------------------|--------------|-----------------|--------------|
| No.1~28          | No.29~56     | No.1~28         | No.29~56     |
| 1236             | 1205         | 1277            | 1272         |
| 1204             | 1191         | 1271            | 1273         |
| 1206             | 1223         | 1277            | 1294         |
| 1197             | 1231         | 1283            | 1295         |
| 1186             | 1200         | 1260            | 1271         |
| 1237             | 1216         | 1299            | 1269         |
| 1219             | 1185         | 1283            | 1254         |
| 1221             | 1231         | 1267            | 1307         |
| 1216             | 1230         | 1278            | 1288         |
| 1200             | 1193         | 1263            | 1269         |
| 1224             | 1188         | 1289            | 1256         |
| 1217             | 1183         | 1296            | 1271         |
| 1208             | 1243         | 1271            | 1294         |
| 1205             | 1243         | 1274            | 1294         |
| 1192             | 1200         | 1258            | 1276         |
| 1218             | 1202         | 1304            | 1274         |
| 1229             | 1184         | 1277            | 1269         |
| 1211             | 1242         | 1276            | 1311         |
| 1197             | 1211         | 1292            | 1294         |
| 1182             | 1202         | 1261            | 1270         |
| 1222             | 1192         | 1289            | 1270         |
| 1202             | 1178         | 1285            | 1267         |
| 1211             | 1221         | 1288            | 1309         |
| 1216             | 1217         | 1269            | 1294         |
| 1195             | 1196         | 1270            | 1279         |
| 1229             | 1206         | 1306            | 1282         |
| 1223             | 1201         | 1295            | 1278         |
| 1201             | 1210         | 1280            | 1283         |

| average 1209     | average 1280 | average 1216    | average 1279 |
|------------------|--------------|-----------------|--------------|

It can be seen from Figure 10. that under normal conditions, the temperature measured by manual is basically consistent with that measured by inspection robot, and only a few of them are quite different. The reasons for these errors are as follows.
Figure 10. Temperature comparison.

(1) In field measurement, there is a little deviation between the manual measurement time and the inspection robot measurement time, which lead to time lag. Although the inspection robot and the surveyor measure temperature at the same time, the measurement speed is different, resulting in time deviation. (2) The pyrometer used for manual measurement is telescope type with an accuracy of 10/1000, while the robot is equipped with an optical fiber pyrometer with an accuracy of 2.5/1000. (3) Manual temperature measurement easily introduces human factors, leading to errors in temperature measurement. (4) Manual temperature measurement and robot inspection temperature measurement both select a certain temperature in the flue. Although both of them choose the most ideal temperature as far as possible, there are still some errors.

5. Conclusion
The system is running continuously in a coking plant of a domestic iron and steel company. The results show that:

(1) Manual temperature measurement is cumbersome, time-consuming and laborious, while the inspection robot can accurately obtain the radial flue temperature, avoid the influence of human factors on the temperature collection, greatly accelerate the temperature measurement speed and save manpower. In addition, The host computer can analyze the data in real time, quickly give the radial temperature, average coefficient and stability coefficient, and display the overall temperature distribution clearly and intuitively, which provides an important basis for the automation of temperature control.

(2) The comparison between the temperature collected by the inspection robot and the manually measured temperature shows that the device can truly and reliably reflect the temperature of the coke oven. The deviation between the temperature collected by the inspection robot and the manually measured temperature is within 10 °C, and the radial temperature is consistent. It can accurately determine the coking chamber with abnormal temperature and remind the operator to make adjustments in time.
(3) Compared with the methods of infrared continuous temperature measurement at furnace top and continuous temperature measurement by embedding thermocouple in flue, the inspection robot realizes the whole furnace temperature collection more simply and economically, and ensures that each temperature data can truly reflect the combustion chamber operation. The operation method is more suitable for the traditional operation habits of coking plant.

6. References
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