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Diagnostic System for Coke-Oven Wall

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The body can be viewed from the next page.

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1 Introduction

The service life of coke ovens is generally about 30-35 years. At Kawasaki Steel also, the oven proper, and in particular, the coking chamber walls, begin to show noticeable deterioration and damage after 25 years of operation. Maintenance is easily accomplished by repairing the damage if the problem is slight, but as the degree of damage becomes more serious, repair costs increase, and in some cases, repair is impossible. Because coking chamber wall deterioration is considered to be the most important factor determining coke-oven life, the most effective measure for extending coke-oven life is the early discovery and prompt repair of wall damage.

Recent years have seen remarkable progress and widespread adoption of flame gunning and other repair techniques for coke ovens. On the other hand, due to the high-temperature environment in the coking chamber, the diagnosis of conditions in the coke oven has depended on visual inspection from outside, supported by expert knowledge. Thus, there were limits to both the early discovery and diagnosis of damaged areas. To solve these problems, we have developed a coke-oven wall diagnostic system, comprising the following hardware and software:

(1) Coking chamber observation equipment in which a camera system is introduced into the coke-oven coking chamber and automatically photographs the entire coke-oven wall.

(2) An image-recognition processing function for coke-oven wall which puts the images taken by the camera into a data base and quantitatively evaluates the condition of the furnace wall.

This report describes the configuration of the system and the image processing algorithm.

2 General Description of Equipment

An outline of the equipment is shown in **Fig. 1**. The system comprises an image input section, which photographs the walls of the coking chamber, and the image processing section, which diagnoses the condition of the oven wall from the photographs taken and files the results.

2.1 Coking Chamber Observations System (Oven Wall Image Input Section)

In developing the coking chamber observation system, a great deal of time was devoted to the study of the device structure and cooling function because the equipment must operate in the coking chamber, where the temperature is approximately 1 000°C. The design and fabrication were conducted in consideration of the following points:

(1) To improve observation efficiency, it should be possible to observe both the right and left walls during one round-trip into the coking chamber.

(2) To minimize the burden on operators, the highest possible level of automation should be adopted in

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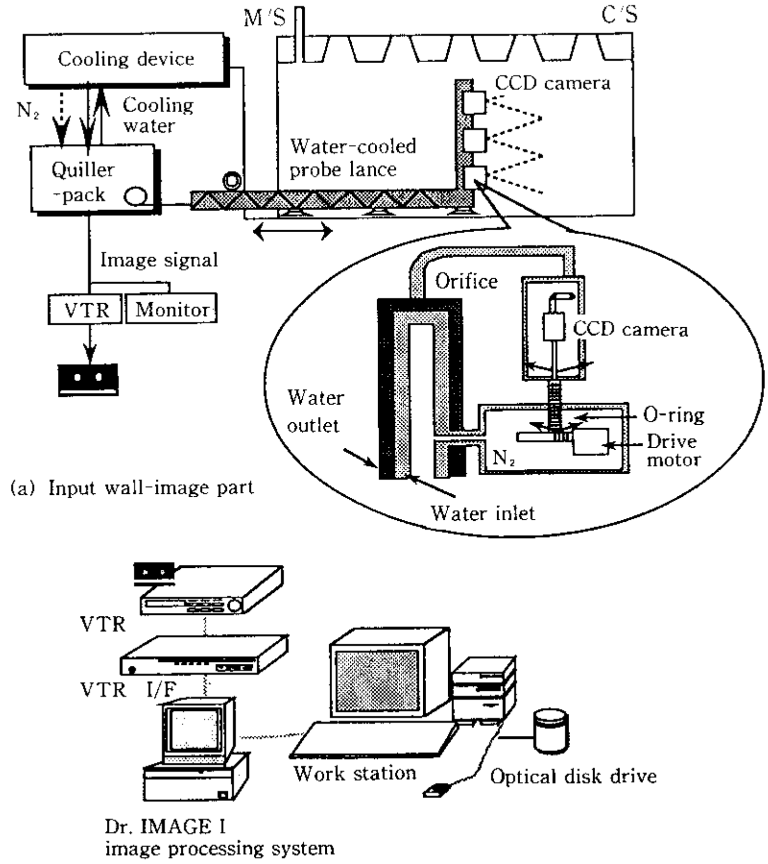


(a) Input wall-image part

(b) Image processing part

Fig. 1 Hardware configuration

the equipment necessary for observation in the coking chamber.

(3) To prevent damage to the oven (coking chamber refractories) and interference with production in case of abnormal functioning of the observation equipment, a safety mechanism should be provided.

As shown in Fig. 1, this image-input section comprises a water-cooled observation boom, a water-cooled probe with an internally mounted CCD camera, a cableveyor, cooling equipment, and a VCR. The special features of the system are described in simple terms in the following.

2.1.1 Lance structure and cooling mechanism

The total length of the lance is approximately 19 m. Of this length, about 16 m is actually introduced into the high-temperature environment of the coking chamber. The lance has an L-shaped configuration to prevent it from buckling under its own weight. Internally, the probe lance is of triple-walled tubular construction. The innermost tube carries the probe wiring and nitrogen for cooling the window at the forward end of the probe. The tube outside this central tube carries the incoming cooling water, and the outermost tube carries the return flow. The probe is equipped with an orifice which is used to adjust the distribution of cooling water, and makes it possible to cool the probe uniformly to a temperature of under 50°C.

2.1.2 Camera swivel mechanism

In order to photograph both the right and left walls of the coking chamber during one round-trip into the chamber, the camera system is provided with a swivel function. The wall on one side of the chamber is photographed as the lance moves into the chamber, and the other side, as the lance is withdrawn, improving the efficiency of wall surface observation. The swivel mechanism is shown in Fig. 1. Cooling water is supplied to the swiveling section through a sliding part with an O-ring. The camera is housed in the cylindrical upper section, which rotates to view both walls.

2.1.3 Automatic operation

Operation of the probe lance was automated in order to lighten the burden on operators in photographing the oven wall. The operations which must be performed by the operator are limited to pusher operation and alignment of the probe with the center of the coking chamber. When these actions have been completed, the operator presses the automatic operation button, initiating the sequence in which the images of the oven wall are automatically recorded on a videocassette.

2.1.4 Safety mechanism

As a safety measure, particularly for abnormalities in the cooling system, the system is equipped with interlocks for the probe internal temperature, cooling water (and N_2) pressure, photographing time, etc.

To prevent heat damage to the equipment and damage to the oven walls due to cooling water leaks, the system is equipped with a mechanism which stops the photographing process and automatically withdraws the probe lance from the coking chamber if an abnormality occurs. In addition, a diesel generator and electric winch are provided as a precaution against power failure, making it possible to quickly retract the probe lance.

2.2 Oven Wall Damage Recognition Section (Image Processing)

The image recognition processing section for oven wall images comprises a work station, image processor, VCR, VCR interface, and magneto-optical (MO) disk. The oven wall images recorded on a videocassette are read into the work station hard disk as digital images via the user interface. Next, the judgment values necessary for evaluating the condition of the furnace wall are obtained using the image processor and the image processing algorithm described in later sections, and a judgment of furnace wall damage is made. The results are displayed, and at the same time, the results and the oven wall images are stored as part of the system data base. The software configuration and a brief outline of each processing step are presented below.

2.2.1 Software configuration

The software in this system is limited to the oven wall image recognition processing section. The videotaped oven wall images obtained by the image input section described above are used in image inputting from the VCR, and hence in image processing, evaluation of results, result indication, and databasing of results and images. All these operations are performed via the user interface on the workstation. A representative window is shown in **Fig. 2**.

2.2.2 Image input from VCR

On the operation window, image index data (oven No., date recorded, inputting method) are to be entered, prior to image input from VCR.

2.2.3 Image processing

The image processing algorithm is used to obtain the judgment values (carbon surface area, number of linear damage, number of planimetric damage) necessary for evaluating the condition of the oven wall, as discussed below, for the image read into the disk by means of the operation window.

2.2.4 Evaluation of results

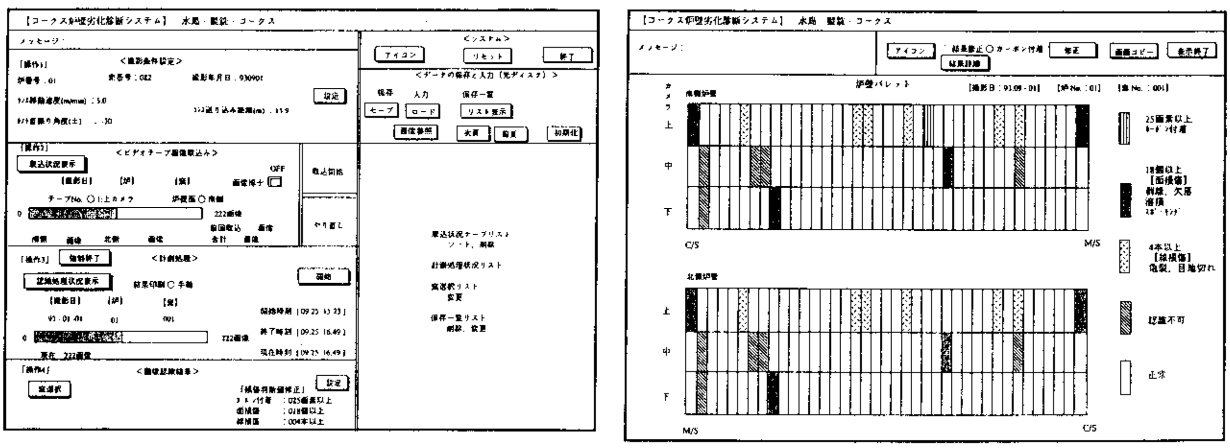
The condition of the furnace wall is evaluated by comparing the judgment values obtained by image processing with standard judgment values set on the operating window.

2.2.5 Display of results

The furnace condition obtained by evaluating the results of image processing is display in a result-display window which images the entire furnace wall. The displayed results can be revised and printed as an image of the oven wall.

2.2.6 Database

The results of evaluation of the condition of the oven wall and the wall images are stored in a magneto-optical disk and can be referenced at later dates.



(a) Operation window (b) Results window

Fig. 2 User interface

3 Image Processing Algorithm

3.1 Categories of Oven Wall Condition

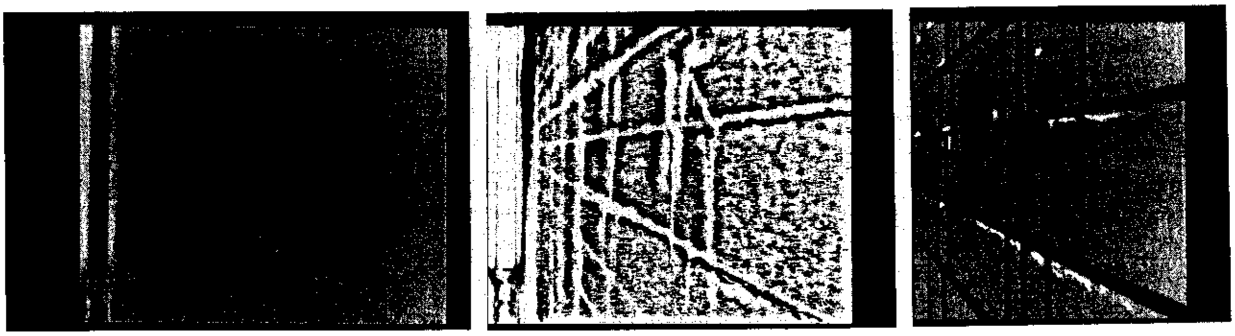
An oven wall image of the type obtained with this system is shown in **Photo 1**. The oven wall image is comprised of the brick surface and brick joints. The oven condition can be classified under a total of ten categories, viz. normal, carbon deposition, brick joint damage, cracks, melting damage, repaired work, spoiling, peeling, fall away of bricks, and other. However, the oven wall images represent in two dimensions a condition which is essentially a three-dimensional space. The ten categories mentioned above cannot be clustered when viewed in a two-dimensional space, and it is therefore difficult to classify these categories by image processing.

To solve this difficulty, the algorithm in this system uses a total of five categories with relatively clear-cut features. These categories are normal, carbon deposition, linear damage (brick joint damage cracks), planimetric damage (melting/spoiling/peeling loss), and other.

3.2 Method of Image Processing

Methods of image processing generally include pattern recognition, texture analysis,[1,2] and the method of specifying the existence of a recognition object based on the total density distribution and other background data. Because images of the coke-oven wall surface have the features listed below, the last of these methods was adopted in the algorithm discussed here.

(1) Coke oven damage does not have a specific characteristic shape.



(a) Original image (b) Binary image (c) Extraction of planimetric damange

Photo 1 Coke oven wall image

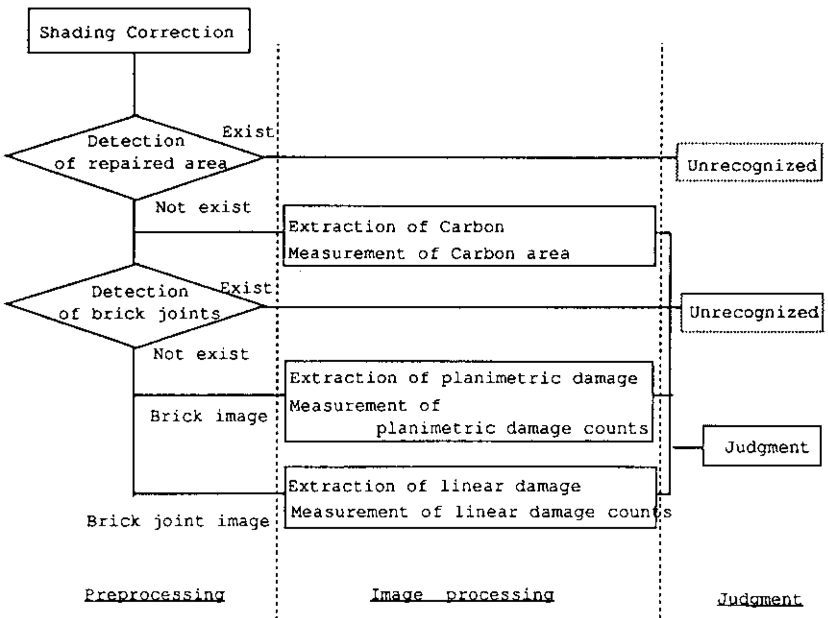


Fig. 3 Flow of the image processing

(2) Adequate discrimination is not possible in a feature space based on texture.
(3) The density range varies in the joints and brick surface.
(4) After removing the gradation covering the entire image, the brick surface area and joints area have flat density respectively.

Therefore, when performing image processing, it is first necessary to distinguish the joints and brick surfaces, as these two oven wall areas have differing density distributions. The condition of the oven wall is then specified from their respective density distributions.

The flow of image processing is shown in **Fig. 3**. The total process can be divided into three stages: preprocessing (shading correction, extraction of joints/brick surface, detection of repaired area), calculation of image feature values (extraction of damaged areas, calculation of number of damage sites), and evaluation of results. In the final stage, a judgment on the results is made using the obtained carbon surface area, number of planimetric damage sites, and number of linear damage sites. A simple explanation of the main image processing techniques is presented below.

3.2.1 Discrimination of joints and brick surface

With this algorithm, the following procedure is used to discriminate the brick joints and brick surface, and judgment values (carbon area, number of linear damage sites, number of planimetric damage sites) are obtained.

(1) Extraction of Candidate Joints

Joints and the brick surface both fall within the specific density range of the entire image. Therefore, a threshold value is obtained by a linear function of the average density, whose parameters were decided experimentally. Because the density range is different when carbon deposition is present, the following threshold values are calculated separately depending on whether carbon is present or not. Binary processing is then used to obtain a binary image such as that in Photo 1.

When carbon present:

$$\left.\begin{array}{l}\text{Threshold value } 1 = m \times 0.6 - 48 \\ \text{Threshold value } 2 = m\end{array}\right\} \cdots\cdots(1)$$

When carbon not present:

$$\left.\begin{array}{l}\text{Threshold value } 1 = m \\ \text{Threshold value } 2 = m - 20\end{array}\right\} \cdots\cdots\cdots\cdots(2)$$

m: average density value

(2) Detection of Horizontal Joints

As can be understood from **Fig. 4**, because horizontal joints are parallel lines in the image, they appear to converge at a certain point (vanishing point) due to the laws of perspective. The present algorithm takes advantage of this vanishing point. Specifically, a triangle with a fixed central angle is rotated around the vanishing point, and when the density distribution in the triangle satisfies a set condition, a joint is judged to be present. The pattern matching method is then used to assign the most appropriate position to the joint.

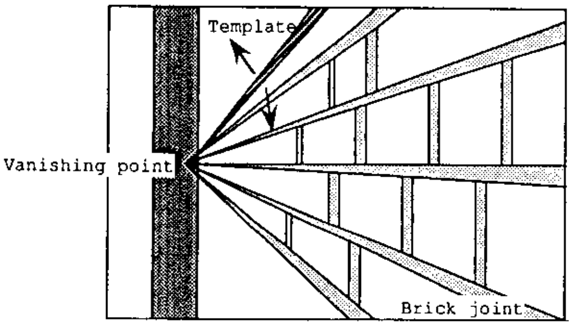


Fig. 4 Extraction of brick joints

To improve reliability, the horizontal joint which has the highest agreement (strength) is first obtained. This line must also exceed the set threshold value. Based on design data, other joints are detected within their relative angle. A secondary differential value of the strength of the joint was evaluated in this algorithm. It should be noted that recognition was not possible if the first line does not exceed the threshold value.

(3) Detection of Vertical Joints

The method of detecting vertical joints is basically the same as for horizontal joints. However, vertical joints do not have a vanishing point. Pattern matching is therefore used, considering the depth between horizontal joints.

3.2.2 Calculation of judgment values

A direct judgment of oven wall condition is not made with this image processing algorithm. Rather, the following three categories of judgment values necessary for evaluating the condition of the oven wall are obtained, and a judgment of these values is made after the operator sets fundamental judgment values on the operating window.

(1) Carbon Area

Carbon has an important effect on the density distribution (density variance) of the entire image. However, convergence on the specific density causes bias in the density distribution. Bias is therefore calculated using Eq. (3):

$$\text{Bias} = \frac{\max - m}{m - \min} \cdots\cdots\cdots\cdots\cdots\cdots(3)$$

max: maximum density
min: minimum density
m: average density value

When the bias is larger than a set threshold value, the presence of adhering carbon is considered possible, and the carbon surface area is calculated. Two kinds of thresholds are used according the average densities. When the average density is low, higher threshold is applied, when the average density is high, lower threshold is applied. Because these parts include normal areas and noise from small white points, such areas must be excluded from the carbon surface area. The density level for extracting the carbon area was obtained using experimental data.

(2) Number of Linear Damage Site
Linear damage includes brick joint damage and cracks in non-joint areas. Where brick joint damage are concerned, an investigation of the density distribution of each joint will reveal large density variance values at joints where breaks have occurred. Using this feature, the number of lines which exceed a certain threshold value for density variation is calculated as a number of linear damage sites. Cracks are detected as the false joints, that have high matching ratio with brick joint template at brick surface locations according to the design data.

(3) Detection of Planimetric Damage
When the brick surface density distribution is examined, planimetric damage visible at the brick surface appears at both ends of the distribution. However, this range includes not only damage but also fine noise. Because the surface damage is large in compairson with the noise, the area containing only surface damage is extracted by eliminating fine particles, and the number of damage sites is calculated. The threshold value was calculated as 2 × the variance value of the distribution, which was obtained experimentally, making it possible to obtain the plaimetric damage detection image in Photo 1.

4 Conclusions

A coke oven wall diagnostic system was developed to solve problems with the conventional method of visual inspection used in examining the coke-oven walls. The new system has the following features:

(1) An oven wall image input device was developed, making it possible to inspect the entire coke-oven wall by introducing a camera into the coking chamber, in spite of the high-temperature environment. The equipment is fabricated with special attention to simple, efficient, safe photography.
(2) The development of an oven wall damage recognition subsystem makes it possible to recognize the condition of the oven wall automatically from recorded images, and to determine the state of damage accurately and at an early stage. Incorporation of the evaluation results and oven wall images in a database makes it possible to assess and predict aging of the coke oven.
(3) An image processing algorithm was developed for recognition of the oven wall condition, making it possible to evaluate the condition of the oven wall quantitatively.
(4) The development of an automatic image input and automatic recognition system have reduced the work load on operators from that required in conventional visual inspection.

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