

DESCRIPTION

Title of Invention

DEVICE AND METHOD FOR OBSERVING ABNORMALITIES IN CIRCULATING
5 FLUIDIZED BED BOILER

Technical Field

[0001]

The present invention relates to a device and a method for
10 observing an abnormality in a circulating fluidized bed boiler.

Background Art

[0002]

An observation system disclosed in PTL 1 is known in the
15 related art. In the observing system, a Mahalanobis distance
of observation target data is calculated, and the presence or
absence of an abnormality in the observation target data is
determined based on the Mahalanobis distance. When it is
determined that there is the abnormality in the observation
20 target data, observation target data having a high rate of
contribution to a larger-the-better characteristic of the
Mahalanobis distance is extracted from the plural pieces of
observation target data as an abnormality signal.

25 Citation List

Patent Literature

[0003]

[PTL 1] Japanese Unexamined Patent Application

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Summary of Invention

Technical Problem

[0004]

In an observation system of a process system such as a power
10 generation plant, there is a technique that determines the
presence or absence of an abnormality in observation target data
using multivariate analysis or data mining. According to the
determination technique, it is possible to determine the
presence or absence of the abnormality due to an already known
15 phenomenon, but for example, it is difficult to determine the
presence or absence of the abnormality due to a phenomenon with
an extremely low occurrence probability such as bursting, or
the presence or absence of the abnormality due to an unknown
phenomenon that has not yet occurred.

20

[0005]

In a system using a technique of a Mahalanobis Taguchi
System (hereinafter, referred to as "MTS"), first, a unit space
is created based on data acquired from the system that is normally
operated. Then, a distance from the center of the unit space
25 to observation target data is calculated as a Mahalanobis

distance. Further, the presence or absence of an abnormality is determined based on the Mahalanobis distance. According to the MTS, it is possible to determine the presence or absence of the abnormality due to a phenomenon with an extremely low occurrence probability, or the presence or absence of the abnormality due to an unknown phenomenon that has not occurred. Furthermore, according to the MTS, it is possible to extract observation target data with a high contribution degree that represents the degree of influence on the Mahalanobis distance from the plural pieces of observation target data.

[0006]

However, in the process system such as a power generation plant, acquirable observation target data is limited, and a water supply and steam system, a fuel and exhaust gas system and the like are combined complicatedly. Accordingly, when the abnormality observation system using the MTS is applied to the process system, a phenomenon that is a cause of the abnormality may not be reliably specified from an abnormality signal.

[0007]

Thus, an object of the invention is to provide a device for observing an abnormality in a circulating fluidized bed boiler capable of reliably specifying a cause of the operation abnormality.

Solution to Problem

[0008]

According to an aspect of the invention, there is provided an abnormality observation device in a circulating fluidized bed boiler, including: operation data acquisition means for acquiring operation data formed of sensor data of the circulating fluidized bed boiler; abnormality determination means for determining the presence or absence of an operation abnormality of the circulating fluidized bed boiler based on a Mahalanobis distance of the operation data; image data acquisition means for acquiring image data of a predetermined imaging portion of the circulating fluidized bed boiler; and data recording means for synchronizing and storing the sensor data and the image data of the imaging portion relating to the sensor data, when the abnormality determination means determines that there is the operation abnormality.

[0009]

According to another aspect of the invention, there is provided a method for observing an abnormality in a circulating fluidized bed boiler, including: an operation data acquisition process of acquiring operation data formed of sensor data of the circulating fluidized bed boiler; an abnormality determination process of determining the presence or absence of an operation abnormality of the circulating fluidized bed boiler based on a Mahalanobis distance of the operation data; an image data acquisition process of acquiring image data of a predetermined imaging portion of the circulating fluidized

bed boiler; and a data recording process for synchronizing and storing the sensor data and the image data of the imaging portion relating to the sensor data, when it is determined that there is the operation abnormality in the abnormality determination
5 process.

[0010]

In the abnormality observation device and the abnormality observation method, the abnormality determination means determines the presence or absence of operation abnormality of
10 the circulating fluidized bed boiler based on the Mahalanobis distance of the operation data for the unit space. Accordingly, even when the abnormality due to an unknown phenomenon occurs, it is possible to determine that there is the operation abnormality in the circulating fluidized bed boiler during
15 operation. Further, the image data acquisition means obtains the image data of the predetermined imaging portion of the circulating fluidized bed boiler. Further, since the data recording means synchronizes and stores the sensor data and the image data of the imaging portion relating to the sensor data,
20 it is possible to analyze the cause of the operation abnormality based on the sensor data and the image data. Accordingly, it is possible to reliably specify the cause of the operation abnormality.

[0011]

25 Further, in the abnormality observation device according

to one aspect of the invention, when it is determined that there is the operation abnormality in the circulating fluidized bed boiler, the abnormality determination means may calculate the contribution degree indicating the degree of influence of each
5 piece of sensor data on the Mahalanobis distance for each piece of sensor data, and the data recording means may synchronize and store the sensor data having the high contribution degree selected based on the contribution degree among the sensor data and the image data of the imaging portion associated with the
10 sensor data having a high contribution degree. In this case, since the sensor data including the possibility of being the cause of the operation abnormality is extracted by calculating the contribution degree for the Mahalanobis distance, it is possible to rapidly specify the cause of the operation
15 abnormality. Further, since the data recording means synchronizes and stores the sensor data having the high contribution degree and the image data of the imaging portion associated with the sensor data, it is possible to analyze the cause of the operation abnormality based on the sensor data
20 having the high contribution degree and the image data. Accordingly, it is possible to reliably and rapidly specify the cause of the operation abnormality.

[0012]

In addition, when the abnormality determination means
25 determines that there is the operation abnormality in the

circulating fluidized bed boiler, data display means for displaying the operation data and the image data in association may be further included. In this case, in a place where it is determined that there is the operation abnormality, it is possible to analyze the cause of the operation abnormality based on the sensor data and the image data.

[0013]

Further, the abnormality observation device according to one aspect of the invention may further include unit space creation means for creating a unit space, and the unit space may be created based on the operation data when the circulating fluidized bed boiler is normally operated.

Advantageous Effects of Invention

[0014]

According to the device and method for observing the abnormality in the circulating fluidized bed boiler of the invention, it is possible to reliably specify the cause of the operation abnormality.

Brief Description of Drawings

[0015]

FIG. 1 is a diagram illustrating a configuration of an abnormality observation device according to an embodiment of the invention.

FIG. 2 is a diagram illustrating an example of operation data acquisition means disposed in a circulating fluidized bed boiler.

FIG. 3 is a diagram illustrating an example of image data acquisition means disposed in the circulating fluidized bed boiler.

FIG. 4 is a diagram illustrating an imaging portion associated with sensor data.

FIG. 5 is a diagram illustrating hardware that forms a part of the abnormality observation device.

FIG. 6 is a diagram illustrating a process of creating a unit space.

FIG. 7 is a diagram illustrating a process of observing the presence or absence of an operation abnormality of the circulating fluidized bed boiler.

FIG. 8 is a diagram illustrating a process of calculating a contribution degree for a Mahalanobis distance.

Description of Embodiments

[0016]

Hereinafter, a device and a method for observing an abnormality in a circulating fluidized bed boiler will be described in detail with reference to the accompanying drawings. The same reference numerals are given to the same components in the description of the drawings, and a repetitive description

will not be made.

[0017]

As shown in FIG. 1, an abnormality observation device 1 according to an embodiment of the invention observes an operation state of a circulating fluidized bed boiler 2 (hereinafter, simply referred to as a "boiler"). First, the boiler 2 will be described. As shown in FIGs. 2 to 4, the boiler 2 is a circulating fluidized bed type boiler. The boiler 2 includes a fluidized bed type furnace 3 that forms a vertically long cylindrical shape. In an intermediate portion of the furnace 3, a fuel supply port 3a through which fuel is input is provided, and in an upper portion thereof, a gas output port 3b through which fuel gas is discharged is provided. The fuel supplied to the furnace 3 from a fuel supply device 5 is supplied into the furnace 3 through the fuel supply port 3a.

[0018]

A cyclone 7 that functions as a device that separates a solid and a gas is connected to the gas output port 3b of the furnace 3. A discharge port 7a of the cyclone 7 is connected to a gas treatment system in a post-stage through a gas line. Further, a return line 9 referred to as a downcomer extends downward from a lower output port of the cyclone 7, and a lower end of the return line 9 is connected to a side surface of the intermediate portion of the furnace 3.

[0019]

In the furnace 3, a solid body including the fuel introduced through the fuel supply port 3a flows by air for combustion and flowing that is introduced from a lower air supply line 3c, and is burned at about 800°C to about 900°C while the fuel is flowing. A combustion gas generated in the furnace 3 is introduced to the cyclone 7 while being accompanied by solid particles. The cyclone 7 separates the solid particles and the gas by a centrifugal separation effect, returns the separated solid particles through the return line 9 to the furnace 3, and transmits the combustion gas from which the solid particles are removed to the gas treatment system in the post-stage through the gas line from the discharge port 7a.

[0020]

In the furnace 3, the solid body called a "fluidizing material in the furnace" is generated and remains at the bottom, and thus, it is necessary to suppress sintering and melt-solidification of the fluidizing material generated as impurities (low melting point material or the like) are concentrated in the fluidizing material, or an operation error due to incombustible foreign matter. Thus, in the furnace 3, the fluidizing material in the furnace is periodically discharged outside through a discharge port 3d at the bottom thereof. After the improper materials such as a metal are removed from a circulation line (not shown), the discharged fluidizing material is introduced to the furnace 3 again.

[0021]

The gas treatment system includes a gas heat exchanger 13 connected to the discharge port 7a of the cyclone 7 through the gas line, and a bag filter (dust collector) 15 connected to a discharge port 13a of the gas heat exchanger 13 through the gas line. The gas heat exchanger 13 is provided with a boiler tube 13b that carries water to cross a flow path of the exhaust gas. As a high temperature exhaust gas transmitted from the cyclone 7 is in contact with the boiler tube 13b, the heat of the exhaust gas is collected in the water inside the tube, and the generated high temperature steam is transmitted to a power generation turbine through the boiler tube 13b. The bag filter 15 removes minute particles such as flying ash or the like that still remain in the combustible gas. The clean gas discharged from a discharge port 15a of the bag filter 15 is discharged outside from a chimney 19 through the gas line and a pump 17.

[0022]

Subsequently, the abnormality observation device 1 will be described. As shown in FIG. 1, the abnormality observation device 1 determines the presence or absence of the operation abnormality of the boiler 2 based on operation data of the boiler 2. Next, when it is determined that there is the operation abnormality in the boiler 2, the abnormality observation device 1 extracts high contribution degree sensor data that is sensor data having a possibility of being a cause of the operation

abnormality. Further, the abnormality observation device 1 synchronizes and records the sensor data and image data acquired by imaging a portion of the boiler 2 associated with the sensor data.

5 [0023]

The abnormality observation device 1 determines the presence or absence of the operation abnormality of the boiler 2 based on the Mahalanobis Taguchi System (MTS) technique. The characteristic of the MTS for the purpose of pattern recognition is in that a unit space is defined and a distance to target data from the center of the unit space is calculated as the Mahalanobis distance. The unit space serves as the center or reference of the pattern recognition. The Mahalanobis distance that is the distance between the center of an existing data group and the target data is calculated using correlation between all variables. Details of the Mahalanobis distance will be described later.

[0024]

The abnormality observation device 1 includes an operation data acquisition part (operation data acquisition means) 21 that acquires operation data, an image data acquisition part (image data acquisition means) 22 that acquires image data, and a data processing part 23 that processes the operation data and the image data as functional components. Hereinafter, functions of the respective components will be described.

[0025]

The operation data acquisition part 21 acquires operation data indicating an operation state of the boiler 2. As described later, a temperature sensor 24, a pressure sensor 26 and the
5 flow rate sensor 27 included in the operation data acquisition part 21 are provided in respective portions of the boiler 2. The operation data refers to a data group formed of sensor data of these sensors. The operation data includes data such as temperatures, pressures, and flow rates of the respective
10 portions of the boiler 2, and indicates the operation state of the boiler 2. The operation data acquired by the operation data acquisition part 21 is output to the data processing part 23.

[0026]

An arrangement example of the temperature sensor 24, the
15 pressure sensor 26, and the flow rate sensor 27 will be described. In the example described hereinafter, temperature sensors 24a to 24d, and 24f to 24k belong to the temperature sensor 24 shown in FIG. 1, pressure sensors 26a to 26d, and 26f to 26k belong to the pressure sensor 26 shown in FIG. 1, and flow rate sensors
20 27e, 27h, and 27j belong to the flow rate sensor 27 shown in FIG. 1.

[0027]

As shown in FIG. 2, in the vicinity of the discharge port 3d of the furnace 3, the temperature sensor 24a and the pressure
25 sensor 26a are disposed. The temperature sensor 24a acquires

temperature data of the lower portion of the furnace 3, and the pressure sensor 26a acquires pressure data of the lower portion of the furnace 3. In the intermediate portion of the furnace 3, the temperature sensor 24b and the pressure sensor 26b are disposed. The temperature sensor 24b acquires temperature data of the intermediate portion of the furnace 3, and the pressure sensor 26b acquires pressure data of the intermediate portion of the furnace 3. On an inner upper surface 3e of the furnace 3, the temperature sensor 24c and the pressure sensor 26c are disposed. The temperature sensor 24c acquires temperature data of the upper portion of the furnace 3, and the pressure sensor 26c acquires pressure data of the upper portion of the furnace 3. The temperature sensor 24d and the pressure sensor 26d are disposed in the gas output port 3b. The temperature sensor 24d acquires temperature data of the discharged gas in the gas output port 3b, and the pressure sensor 26d acquires pressure data of the discharged gas in the gas output port 3b.

[0028]

The flow rate sensor 27e is disposed in the air supply line 3c. The flow rate sensor 27e acquires flow rate data of air that flows through the air supply line 3c.

[0029]

In the vicinity of the heat exchange part 13c of the gas heat exchanger 13, the temperature sensor 24f and the pressure sensor 26f are disposed. The temperature sensor 24f acquires

temperature data of the exhaust gas in the gas heat exchanger 13, and the pressure sensor 26f acquires pressure data of the exhaust gas in the gas heat exchanger 13. In the vicinity of the discharge port 13a of the gas heat exchanger 13, the temperature sensor 24g and the pressure sensor 26g are disposed. The temperature sensor 24g acquires temperature data of the exhaust gas discharged from the discharge port 13a, and the pressure sensor 26g acquires pressure data of the exhaust gas discharged from the discharge port 13a.

10 [0030]

On an upstream side from the heat exchange part 13c of the gas heat exchanger 13, the temperature sensor 24h and the flow rate sensor 27h are disposed. The temperature sensor 24h acquires temperature data of the water in the tube before the heat of the exhaust gas is collected, and the flow rate sensor 27h acquires flow rate data of the water in the tube before the heat of the exhaust gas is collected. On a downstream side of the boiler tube 13b from the heat exchange part 13c, the temperature sensor 24j, the pressure sensor 26j, and the flow rate sensor 27j are disposed. The temperature sensor 24j acquires temperature data of the steam in the tube, the pressure sensor 26j acquires pressure data of the steam in the tube, and the flow rate sensor 27j acquires flow rate data of the steam in the tube.

25 [0031]

In the vicinity of the discharge port 15a of the bag filter 15, the temperature sensor 24k and the pressure sensor 26k are disposed. The temperature sensor 24k acquires temperature data of the exhaust gas in the vicinity of the discharge port 15a, and the pressure sensor 26k acquires pressure data of the exhaust gas in the vicinity of the discharge port 15a.

[0032]

As shown in FIG. 1, the image data acquisition part 22 acquires image data of a predetermined imaging portion of the boiler 2. As described later, plural cameras 28 included in the image data acquisition part 22 are provided in the respective portions of the boiler 2. The image data refers to image data of the predetermined imaging portion of the boiler 2 captured by these cameras 28. The image data may be a still image or a moving image. The image data acquired in the image data acquisition part 22 is output to the data processing part 23.

[0033]

The example of the predetermined imaging portion and the arrangement example of the cameras for imaging the imaging portion will be described. In the example described hereinafter, the plural cameras 28a to 28e belong to the camera 28 shown in FIG. 1. As shown in FIG. 3, as the predetermined imaging portions, there are a portion 16a in the vicinity of the discharge port 3d of the furnace 3 and a portion 16b on a side wall surface of the furnace 3. Further, as the predetermined imaging

portions, there are a portion 16c of the heat exchange part 13c of the gas heat exchanger 13, a portion 16d of the boiler tube 13b on the upstream side of the heat exchange part 13c, and a portion 16e of the boiler tube 13b on the downstream side of the heat exchange part 13c. The camera 28a for imaging the portion 16a is disposed in the vicinity of the fuel supply port 3a of the furnace 3. The camera 28b for imaging the portion 16b is disposed on an inner wall of the furnace 3 that faces a side wall surface that is an imaging target. The camera 28c for imaging the portion 16c is arranged on an inner wall of the gas heat exchanger 13 that faces the heat exchange part 13c. The camera 28d for imaging the portion 16d is disposed in the vicinity of the portion 16d. The camera 28e for imaging the portion 16e is disposed in the vicinity of the portion 16e.

[0034]

Here, an example of image data associated with sensor data will be described. As shown in FIG. 4, the camera 28c for imaging the heat exchange part 13c of the gas heat exchanger 13 is associated with the exhaust gas temperature data of the temperature sensor 24f provided in the vicinity of the heat exchange part 13c of the gas heat exchanger 13 and the exhaust gas pressure data of the pressure sensor 26f. That is, when there is the abnormality in the exhaust gas temperature data acquired in the temperature sensor 24f and/or the exhaust gas pressure data acquired in the pressure sensor 26f, there is a high

possibility that there is the abnormality in the heat exchange part 13c that is the water supply and steam tube. Accordingly, image data of the heat exchange part 13c captured by the camera 28c is associated with the exhaust gas temperature data acquired by the temperature sensor 24f and the exhaust gas pressure data acquired by the pressure sensor 26f.

[0035]

As shown in FIG. 1, the data processing part 23 processes the sensor data input through the operation data acquisition part 21 to determine the presence or absence of the operation abnormality of the boiler 2. Further, when it is determined that there is the operation abnormality, the data processing part 23 synchronizes and records the image data input through the image data acquisition part 22 and the sensor data. Further, when it is determined that there is the operation abnormality, the data processing part 23 outputs a command for displaying in synchronization the image data and the sensor data in a display part (data display means) 31 to be described later, to the display part 31. Further, the data processing part 23 acquires in advance operation data when the boiler 2 is normally operated, and creates the unit space used for determination of the operation abnormality by the MTS technique to be described later based on the operation data. The data processing part 23 is realized using a computer 100 shown in FIG. 5, for example.

[0036]

As shown in FIGs. 1 and 5, the computer 100 is an example of hardware formed by the data processing part 23 according to the embodiment of the invention. The computer 100 includes various data processing devices such as a server device or a personal computer that is provided with a CPU and performs processes or controls by software. The computer 100 is formed as a computer system that includes a CPU 41, a RAM 42 and a ROM 43 that are main storage devices, an input device 44 such as a keyboard or a mouse that is an input device, an output device 46 such as a display, a communication module 47 that is a data transmission/reception device such as a network card, an auxiliary storage device 48 such as a hard disk, and the like. The input device 44 forms the input part 29 to be described later, and the output device 46 forms the display part 31 to be described later (see FIG. 1). The functional components shown in FIG. 1 are realized as the hardware such as the CPU 41 and the RAM 42 shown in FIG. 5 reads predetermined computer software to operate the input device 44, the output device 46, and the communication module 47 under the control of the CPU 41, and as reading and writing of data in the RAM 42 or the auxiliary storage device 48 are performed.

[0037]

As shown in FIG. 1, to the data processing part 23, the sensor data is input from the operation data acquisition part 21, and the image data is input from the image data acquisition

part 22. The data processing part 23 includes a unit space creator (unit space creation means) 32 that creates the unit space, a temporary recorder 33 that temporarily records operation data for a predetermined period of time, an abnormality determination part (abnormality determination means) 34 that determines the presence or absence of the operation abnormality and calculates a contribution degree when it is determined that there is the operation abnormality, and an operation data synchronization recorder (data recording means) 36 that synchronizes and records the sensor data and the image data.

[0038]

The unit space creator 32 collects the sensor data during a normal operation to create the unit space. Further, the unit space creator 32 calculates and records a matrix used for calculation of the Mahalanobis distance based on the unit space. Further, the unit space creator 32 outputs the matrix based on the unit space to the abnormality determination part 34 so that the abnormality determination part 34 refers to the matrix when calculating the Mahalanobis distance.

[0039]

The temporary recorder 33 has a function of recording the operation data output from the operation data acquisition part 21 and the image data output from the image data acquisition part 22 for a predetermined period of time. Further, when the abnormality determination part 34 determines that there is the

operation abnormality, the temporary recorder 33 outputs in synchronization the sensor data and the image data for several seconds to several minutes around an abnormality occurrence time to the operation data synchronization recorder 36.

5 [0040]

 The abnormality determination part 34 calculates the Mahalanobis distance based on the sensor data output from the temporary recorder 33 and the matrix based on the unit space output from the unit space creator 32. Further, the abnormality
10 determination part 34 compares a threshold value recorded in the abnormality determination part 34 in advance with the Mahalanobis distance, and when the Mahalanobis distance exceeds the threshold value, determines that there is the operation
15 abnormality in the boiler 2. When it is determined that there is the operation abnormality, the abnormality determination part 34 calculates a contribution degree indicating the degree of influence on the Mahalanobis distance for each piece of sensor data, and extracts the sensor data having a high contribution degree. Further, the abnormality determination part 34 outputs
20 a command to the temporary recorder 33 so as to synchronize and record the sensor data having the high contribution degree, the image data associated with the sensor data having the high contribution degree, and the Mahalanobis distance. Furthermore, the abnormality determination part 34 outputs the sensor data
25 having the high contribution degree and the image data to the

display part 31 to display the sensor data having the high contribution degree and the image data.

[0041]

The operation data synchronization recorder 36

5 synchronizes and records the sensor data output from the temporary recorder 33, the image data, and the Mahalanobis distance of the operation data for the unit space. The data recorded in the operation data synchronization recorder 36 is used as analysis data when the cause of the operation abnormality
10 is analyzed. In the operation data synchronization recorder 36, each piece of data may be compressed to be recorded. Further, in the operation data synchronization recorder 36, the sensor data having the high contribution degree and the image data associated with the sensor data having the high contribution
15 degree may be recorded, or the entire data acquired by the operation data acquisition part 21 and the image data acquisition part 22 may be recorded.

[0042]

The data processing part 23 may include the input part 29
20 and the display part 31 as necessary. The input part 29 is configured to have an input device such as a microphone. A threshold value or the like necessary for data processing is input through the input part 29. The display part 31 is configured to have an image display device such as a CRT display
25 or a liquid crystal display. In the display part 31, information

indicating that the operation abnormality occurs is displayed,
the sensor data having the high contribution degree and the image
data output from the abnormality determination part 34, or the
like is displayed. The display part 31 may further include a
5 bell, a sound speaker, a lighting lamp, an LED, or the like in
order to reliably inform the occurrence of the operation
abnormality, and may inform the occurrence of the operation
abnormality using this component.

[0043]

10 Next, the abnormality observation method based on the MTS
technique using the abnormality observation device 1 will be
described. The abnormality observation method includes step
S10 of creating the unit space shown in FIG. 6, step S20 of
observing the operation state shown in FIG. 7, and step S25 of
15 analyzing the cause shown in FIG. 8.

[0044]

<Unit space creation step S10>

Step S10 of creating the unit space will be described with
reference to FIG. 6. Step S10 is mainly performed by the unit
20 space creator 32 of the data processing part 23. Since an object
of the abnormality observation method of the present embodiment
is to determine the presence or absence of the operation
abnormality of the boiler 2, the unit space of the present
embodiment is a set of operation data acquired from the boiler
25 2 that is normally operated. In step S10, a matrix A necessary

for calculation of a Mahalanobis distance D^2 is created from the unit space that is the group of the operation data. Step S10 is executed before the start of step S20 of observing the operation abnormality. Further, step S10 may be executed at every predetermined period, for example, every year, or may be executed at an arbitrary time. That is, it is sufficient if the matrix A can be created as step S10 is executed before step S20 of observing the operation state is executed.

[0045]

10 The operation data is acquired in step S11. The operation data represents operation data on the normally operated boiler 2. In step S11, the operation data is acquired while an operator confirms that there is no operation abnormality in the operated boiler 2. Then, in step S12, the acquired operation data is added to the unit space. Subsequently, in step S13, it is determined whether the number of pieces of data accumulated in the unit space satisfies the number of pieces of data necessary for creating the matrix A. More specifically, in step S13, when k pieces of sensor data x_1 to x_k are included in the operation data, 15 it is determined whether the number of pieces of data n of the operation data is equal to or greater than k. When the number of pieces of data n is smaller than k (NO), the procedure returns to step S11, and the operation data is further acquired. When the number of pieces of data n is equal to or greater than k (YES), the matrix A is created in step S14. 20 25

[0046]

Step S14 of creating the matrix A will be described in detail. The matrix A is an inverse matrix $A=R^{-1}$ of a correlation matrix R that uses a correlation coefficient between the
5 respective pieces of sensor data x_1 to x_k as a component. First, the sensor data x_1 to x_k is standardized. The standardization of the sensor data x_1 to x_k is performed by Expression (1). In the standardized sensor data X_1 to X_k , an average value is zero, and a standard deviation is 1.

10 [Expression 1]

$$X_{ij} = \frac{x_{ij} - \overline{x_{ij}}}{\sigma_j} \quad \cdots (1)$$

Next, the correlation matrix R is calculated. As indicated by Expression (2), the correlation matrix is a $k \times k$ square matrix. Each component r_{ij} of the correlation matrix R
15 is a correlation coefficient of standardized sensor data X_i and standardized sensor data X_j .

[Expression 2]

$$R = \begin{bmatrix} r_{11} & \cdots & r_{1k} \\ \vdots & \ddots & \vdots \\ r_{1k} & \cdots & r_{kk} \end{bmatrix} \quad \cdots (2)$$

Next, the inverse matrix A of the correlation matrix R
20 indicated by Expression (3) is calculated.

[Expression 3]

$$R^{-1} = A = \begin{bmatrix} r_{11} & \cdots & r_{1k} \\ \vdots & \ddots & \vdots \\ r_{1k} & \cdots & r_{kk} \end{bmatrix}^{-1} \quad \cdots (3)$$

[0047]

The matrix A created in step S14 is recorded in the unit space creator 32, and is referred to by the abnormality determination part 34 when the Mahalanobis distance D^2 to be described later is calculated.

[0048]

<Abnormality observation step S20>

Abnormality observation step S20 of observing the operation state of the boiler 2 will be described with reference to FIG. 7. Step S20 is mainly performed by the abnormality determination part 34 of the data processing part 23. First, in step S21 (operation data acquisition process and image data acquisition process), the operation data is acquired by the temperature sensors 24a to 24d, and 24f to 24k, the pressure sensors 26a to 26d, and 26f to 26k, and the flow rate sensors 27e, 27h, and 27j that are disposed in the respective parts of the boiler 2. Further, in addition to the acquisition of the operation data, the image data is acquired by the cameras 28a to 28e. The acquired operation data and image data are recorded in the temporary recorder 33. Further, the operation data recorded in the temporary recorder 33 is transmitted to the abnormality determination part 34. Then, in step S22, the

Mahalanobis distance D^2 of the operation data is calculated.

[0049]

Here, the Mahalanobis distance D^2 will be described. The Mahalanobis distance D^2 is used as a reference to measure the distance from the center of a distribution having an arbitrary variance. For example, the Mahalanobis distance D^2 having one variable is indicated as Expression (4).

[Expression 4]

$$D^2 = \frac{(x - \text{average})^2}{\text{variance}} = \frac{(x - \bar{x})^2}{s^2} \quad \dots (4)$$

In the present embodiment, the number of the pieces of sensor data x_1 to x_k that serve as the variable is not one, but for example, is k . Expression (4) is modified to an expression having k variables. The Mahalanobis distance D^2 indicated as Expression (4) is modified as shown in Expression (5).

[Expression 5]

$$\begin{aligned} D^2 &= (x - \bar{x}) \cdot \frac{1}{s^2} \cdot (x - \bar{x}) \quad \dots (5) \\ &= (x - \bar{x}) \cdot (s^2)^{-1} \cdot (x - \bar{x}) \end{aligned}$$

The first term and the third term in the above expression are re-written in the format of vectors, and the second term is re-written to a variance-covariance matrix.

[Expression 6]

$$D^2 = \begin{bmatrix} x_1 - \bar{x}_1 & \dots & x_k - \bar{x}_k \end{bmatrix} \begin{bmatrix} s_{11} & \dots & s_{1k} \\ \vdots & \ddots & \vdots \\ s_{1k} & \dots & s_{kk} \end{bmatrix}^{-1} \begin{bmatrix} x_1 - \bar{x}_1 \\ \vdots \\ x_k - \bar{x}_k \end{bmatrix} \quad \dots (6)$$

Here, the covariance s_{ij} of the variable i and the variable j is expressed as Expression (7) by the correlation coefficient r_{ij} .

[Expression 7]

$$r_{ij} = \frac{s_{ij}}{\sigma_i \sigma_j} \quad \dots \quad (7)$$

5

Accordingly, if the Mahalanobis distance D^2 is expressed as Expression (8) by the correlation coefficient.

[Expression 8]

$$D^2 = \begin{bmatrix} \frac{x_1 - \bar{x}_1}{\sigma_1} & \dots & \frac{x_k - \bar{x}_k}{\sigma_k} \end{bmatrix} \begin{bmatrix} r_{11} & \dots & r_{1k} \\ \vdots & \ddots & \vdots \\ r_{1k} & \dots & r_{kk} \end{bmatrix}^{-1} \begin{bmatrix} \frac{x_1 - \bar{x}_1}{\sigma_1} \\ \vdots \\ \frac{x_k - \bar{x}_k}{\sigma_k} \end{bmatrix} \quad \dots \quad (8)$$

10

Further, if the sensor data x_1 to x_k in Expression (8) is expressed as standardized sensor data X_1 to X_k (see Expression (9)), Expression (8) is indicated as Expression (10).

[Expression 9]

$$X_k = \frac{x_k - \bar{x}_k}{\sigma_k} \quad \dots \quad (9)$$

15

[Expression 10]

$$D^2 = \begin{bmatrix} X_1 & \dots & X_k \end{bmatrix} \begin{bmatrix} r_{11} & \dots & r_{1k} \\ \vdots & \ddots & \vdots \\ r_{1k} & \dots & r_{kk} \end{bmatrix}^{-1} \begin{bmatrix} X_1 \\ \vdots \\ X_k \end{bmatrix} \quad \dots \quad (10)$$

If Expression (10) is divided by the number k of the variables, the Mahalanobis distance D^2 is indicated as Expression (11).

[Expression 11]

$$D^2 = [X_1 \quad \cdots \quad X_k] \begin{bmatrix} r_{11} & \cdots & r_{1k} \\ \vdots & \ddots & \vdots \\ r_{1k} & \cdots & r_{kk} \end{bmatrix}^{-1} \begin{bmatrix} X_1 \\ \vdots \\ X_k \end{bmatrix} / k \quad \cdots (11)$$

In step S22, the sensor data x_1 to x_k is respectively converted into the standardized sensor data X_1 to X_k . Further, the standardized sensor data X_1 to X_k and the matrix A are applied to Expression (11) to calculate the Mahalanobis distance D^2 .

[0050]

Subsequently, in step S23 (abnormality determination process), the Mahalanobis distance D^2 is compared with a threshold value. The threshold value is input through the input part 29, for example, and is recorded in the abnormality determination part 34 in advance. The threshold value is set as a desired value in advance. When the Mahalanobis distance D^2 is smaller than the threshold value (NO), it is determined that there is no operation abnormality, and the procedure goes to step S28.

[0051]

On the other hand, when the Mahalanobis distance D^2 is equal to or greater than the threshold value (YES), it is determined that there is the operation abnormality, and the procedure goes to step S25. Further, in step S25, sensor data or a set of sensor data that may be the cause of the operational abnormality among the sensor data x_1 to x_k included in the operation data is extracted.

[0052]

<Cause analysis step S25>

Cause analysis step S25 of analyzing the cause of the operation abnormality will be described with reference to FIG.

5 8. In cause analysis step S25, when the Mahalanobis distance D^2 exceeds the threshold value in step S23 of the abnormality observation step S20, the sensor data x_1 to x_k or the set of the sensor data x_1 to x_k that contribute to increase of the Mahalanobis distance D^2 is analyzed.

10 [0053]

In step S25a, the pieces of sensor data x_1 to x_k that are cause analysis targets are acquired. Here, the pieces of sensor data x_1 to x_k are sensor data x_1 to x_k that form the Mahalanobis distance that exceeds the threshold value in step S23.

15 [0054]

Next, an orthogonal table is created in step S25b. The orthogonal table is a table obtained by compressing many combinations rationally and systematically. An orthogonal table that is generally used in cause analysis of MTS is an
20 orthogonal table of a double level system. Table 1 is an example of an orthogonal table when the operation data is configured to have seven pieces of sensor data x_1 to x_7 .

[Table 1]

↑ Sample Number ↓	Sensor data							
	No.	x ₁	x ₂	x ₃	x ₄	x ₅	x ₆	x ₇
	1	1	1	1	1	1	1	1
	2	1	1	1	2	2	2	2
	3	1	2	2	1	1	2	2
	4	1	2	2	2	2	1	1
	5	2	1	2	1	2	1	2
	6	2	1	2	2	1	2	1
	7	2	2	1	1	2	2	1
	8	2	2	1	2	1	1	2

[0055]

Subsequently, in step S25c, the SN ratio of a larger-the-better characteristic is calculated. It is desirable that the Mahalanobis distance D^2 of the sensor data that does not belong to the unit space, that is, the sensor data that becomes the cause of the operation abnormality be large. In this way, when a characteristic which is considered to be better as a value thereof is larger the characteristic is referred to as the larger-the-better characteristic. Further, since the plural pieces of the sensor data are present, the variance is generally present. The SN ratio is acquired by quantifying the desirability including the variance. The SN ratio is calculated by Expression (12).

[Expression 12]

$$\eta = -10 \log \left\{ \frac{(1/D_1^2 + 1/D_2^2 + \dots + 1/D_m^2)}{m} \right\} \quad \dots (12)$$

[0056]

The procedure of calculating the SN ratio in step S25c will

be described in detail. In the orthogonal table in Table 1, referring to the first row showing the number of pieces of data, the first row represents that the entire pieces of sensor data x_1 to x_7 are in a first level. Accordingly, the Mahalanobis distance D_1^2 is calculated using the entire sensor data x_1 to x_7 . Subsequently, referring to the second row of the orthogonal table in Table 1, the second row represents that the pieces of sensor data x_1 to x_3 are in the first level and the pieces of sensor data x_4 to x_7 are in a second level. Accordingly, the Mahalanobis distance D_2^2 is calculated using the sensor data x_1 to x_3 . Thereafter, in the third row to the eighth row of the orthogonal table in Table 1, the Mahalanobis distances D_3^2 to D_8^2 corresponding to the respective rows are calculated in the same way.

[0057]

Subsequently, the SN ratio is calculated for each piece of sensor data x_1 to x_7 . Here, the SN ratio of the first level and the SN ratio of the second level are calculated for each piece of sensor data x_1 to x_7 . Here, the SN ratio of the first level refers to the SN ratio calculated using the Mahalanobis distance in the sample number in which the SN ratio is the first level, among the Mahalanobis distances D_1^2 to D_8^2 . Further, the SN ratio of the second level refers to the SN ratio calculated using the Mahalanobis distance in the sample number in which the SN ratio is the second level, among the Mahalanobis distances

D_1^2 to D_8^2

[0058]

For example, in the case of the sensor data x_1 , the sample number in which the SN ratio is the first level corresponds to

5 1 to 4. Accordingly, the SN ratio of the first level is

calculated using the Mahalanobis distances D_1^2 to D_4^2 . Further, the sample number in which the SN ratio is the second level corresponds to 5 to 8. Accordingly, the SN ratio of the second level is calculated using the Mahalanobis distances D_5^2 to D_8^2 .

10 The SN ratio η_{A1} of the first level of the sensor data x_1 is calculated by Expression (13). Further, the SN ratio η_{A2} of the second level of the sensor data x_1 is calculated by Expression (14).

[Expression 13]

$$\eta_{A1} = -10 \log \left\{ \frac{(1/D_1^2 + 1/D_2^2 + 1/D_3^2 + 1/D_4^2)}{4} \right\} \quad \dots (13)$$

15

[Expression 14]

$$\eta_{A2} = -10 \log \left\{ \frac{(1/D_5^2 + 1/D_6^2 + 1/D_7^2 + 1/D_8^2)}{4} \right\} \quad \dots (14)$$

[0059]

In step S25d, the contribution degree is calculated. In consideration of the sensor data x_1 , when a difference between the SN ratio η_{A1} of the first level and the SN ratio η_{A2} of the second level is large in a forward direction, this means that

the sensor data x_1 has a possibility of being a cause of the operation abnormality. The difference ($\eta_{A1} - \eta_{A2}$) between the SN ratio η_{A1} of the first level and the SN ratio η_{A2} of the second level is referred to as the contribution degree. Thereafter,
5 the contribution degrees of the sensor data x_2 to x_8 are calculated in the same way.

[0060]

The contribution degree is calculated for each piece of sensor data x_1 to x_7 by the above-described processes S25a to
10 S25d. The sensor data having the highest contribution degree or the sensor data that exceeds a predetermined threshold value of the contribution degree is extracted as sensor data having a high contribution degree or a set of the sensor data having the high contribution degree.

15 [0061]

Referring to FIG. 7 again, in step S26 (data recording process), the sensor data and the image data are synchronized and recorded. Step S26 is mainly executed by the operation data synchronization recorder 36. Information about the sensor data
20 extracted as the sensor data having the high contribution degree in step S25 is output to the temporary recorder 33 from the abnormality determination part 34. The temporary recorder 33 outputs in synchronization the sensor data extracted as the sensor data having the high contribution degree and the image
25 data associated with the sensor data, based on the information

output from the abnormality determination part 34, to the operation data synchronization recorder 36. Further, the operation data synchronization recorder 36 records the sensor data and the image data output from the temporary recorder 33.

5 [0062]

Further, in step S27, information indicating that there is the operation abnormality is displayed in the display part 31. Step S27 is mainly executed by the display part 31. The information indicating that there is the operation abnormality is output to the display part 31 from the abnormality determination part 34, and the display part 31 informs that there is the operation abnormality based on the information. Further, the sensor data extracted as the sensor data having the high contribution degree and the image data of the camera associated with the sensor data are output to the display part 31 from the abnormality determination part 34, and are displayed in the display part 31.

[0063]

In step S28, it is determined whether the abnormality observation step S20 is to be terminated. When it is determined that the abnormality observation step S20 is not to be terminated (NO), that is, when the abnormality observation operation is continued, the procedure goes to step S21, and then, the operations from step S21 are performed again. When it is determined that the abnormality observation step S20 is to be

terminated (YES), the abnormality observation step S20 is terminated.

[0064]

As described above, in the device and method for observing
5 the abnormality in the circulating fluidized bed boiler
according to the present embodiment, in step S23, the abnormality
determination part 34 determines the presence or absence of the
operation abnormality of the boiler 2, based on the Mahalanobis
distance of the operation data for the unit space calculated
10 in step S22. Accordingly, even when the operation abnormality
due to an unknown phenomenon occurs, it is possible to determine
that there is the operation abnormality in the boiler 2 during
operation. Further, the image data of the predetermined imaging
portions 16a to 16e of the boiler 2 is acquired by the camera
15 28 of the image data acquisition part 22. Further, in step S26,
the operation data synchronization recorder 36 synchronizes and
stores the sensor data having the high contribution degree and
the image data of the imaging portion relating to the sensor
data. Accordingly, it is possible to analyze the cause of the
20 operation abnormality based on the sensor data and the image
data. Accordingly, it is possible to reliably specify the cause
of the operation abnormality.

[0065]

Further, in the device and method for observing the
25 abnormality in the circulating fluidized bed boiler according

to the present embodiment, in step S25, the contribution degree for the Mahalanobis distance is calculated. Accordingly, since the sensor data including the possibility of being the cause of the operation abnormality is extracted, it is possible to rapidly specify the cause of the operation abnormality. In addition, in step S26, since the data recording means synchronizes and stores the sensor data having the high contribution degree and the image data of the imaging portion associated with the sensor data, it is possible to analyze the cause of the operation abnormality based on the sensor data having the high contribution degree and the image data. Accordingly, it is possible to reliably and rapidly specify the cause of the operation abnormality.

[0066]

Further, the abnormality observation device 1 of the circulating fluidized bed boiler according to the present embodiment includes the display part 31. Accordingly, in a place where it is determined that there is the operation abnormality, it is possible to analyze the cause of the operation abnormality based on the sensor data and the image data.

[0067]

In the above-described embodiments, the examples of the abnormality observation device 1 and the abnormality observation method are shown. The abnormality observation device 1 and the abnormality observation method according to

the invention are not limited to the above-described embodiments,
and the abnormality observation device 1 and the abnormality
observation method according to the above-described embodiments
may be modified or may be used in other applications in a range
5 without departing from the scope disclosed in claims.

[0068]

The sensor data may use data other than the temperature
data, the pressure data and the flow rate data. For example,
a desired concentration of a material included in the exhaust
10 gas, such as an oxygen concentration, NO_x concentration, CO
concentration, or SO₂ concentration, or a fuel supply amount
supplied through the fuel supply port 3a may be used. Further,
the places where the temperature sensor 24, the pressure sensor
26, the flow rate sensor 27, and the camera 28 are disposed may
15 be changed to other places.

Industrial Applicability

[0069]

According to the abnormality observation device 1 of the
20 circulating fluidized bed boiler and the abnormality
observation method thereof, it is possible to reliably specify
the cause of the operation abnormality.

Reference Signs List

25 [0070]

	1	Abnormality observation device
	2	Circulating fluidized bed boiler
	21	Operation data acquisition part (operation data acquisition means)
5	22	Image data acquisition part (image data acquisition means)
	23	Data processing part
	24	Temperature sensor
	26	Pressure sensor
10	27	Flow rate sensor
	28	Camera
	29	Input part
	31	Display part (data display means)
	32	Unit space creator (unit space creation means)
15	33	Temporary recorder
	34	Abnormality determination part (abnormality determination means)
	36	Operation data synchronization recorder (data recording means)
20	100	Computer
	D^2	Mahalanobis distance
	x_1 to x_k	Sensor data
	S10	Unit space creation process
	S20	Abnormality observation process
25	S25	Cause analysis process

CLAIMS

1. An abnormality observation device in a circulating fluidized bed boiler, comprising:

5 operation data acquisition means for acquiring operation data formed of sensor data of the circulating fluidized bed boiler;

 abnormality determination means for determining the presence or absence of an operation abnormality of the
10 circulating fluidized bed boiler based on a Mahalanobis distance of the operation data;

 image data acquisition means for acquiring image data of a predetermined imaging portion of the circulating fluidized bed boiler; and

15 data recording means for synchronizing and storing the sensor data and the image data of the imaging portion relating to the sensor data, when the abnormality determination means determines that there is the operation abnormality.

20 2. The abnormality observation device in a circulating fluidized bed boiler according to claim 1,

 wherein the abnormality determination means calculates, when it is determined that there is the operation abnormality in the circulating fluidized bed boiler, a contribution degree
25 indicating the degree of influence of each piece of sensor data

on the Mahalanobis distance for each piece of sensor data, and
wherein the data recording means synchronizes and stores
the sensor data having a high contribution degree selected based
on the contribution degree among the sensor data and the image
5 data of the imaging portion associated with the sensor data
having the high contribution degree.

3. The abnormality observation device in a circulating
fluidized bed boiler according to claim 1 or 2, further
10 comprising:

data display means for displaying the operation data and
the image data in association when the abnormality determination
means determines that there is the operation abnormality in the
circulating fluidized bed boiler.

15

4. The abnormality observation device in a circulating
fluidized bed boiler according to any one of claims 1 to 3,
further comprising:

unit space creation means for creating a unit space based
20 on the operation data when the circulating fluidized bed boiler
is normally operated.

5. A method for observing an abnormality in a circulating
fluidized bed boiler, comprising:

25 an operation data acquisition process of acquiring

operation data formed of sensor data of the circulating fluidized bed boiler;

an abnormality determination process of determining the presence or absence of an operation abnormality of the circulating fluidized bed boiler based on a Mahalanobis distance of the operation data;

an image data acquisition process of acquiring image data of a predetermined imaging portion of the circulating fluidized bed boiler; and

a data recording process for synchronizing and storing the sensor data and the image data of the imaging portion relating to the sensor data, when it is determined that there is the operation abnormality in the abnormality determination process.