JFE TECHNICAL REPORT
No. 28 (Sep. 2022)

Construction of Fukuyama No. 3 Sinter Plant and Application of Data Science Technology

TAKEUCHI Naoyuki[*1] MATSUSHITA Masafumi[*2] GION Hiroki[*3] MIYAZAWA Toru[*4] HASHIMOTO Ken[*5] FUKAGAWA Kenichi[*6]

Abstract:

In December 2019, No. 3 Sinter Plant started operation by using state-of-the-art sinter machine, exhausted gas treatment system and DS (Data Science) technology at JFE Steel West Japan Works (Fukuyama District). Until now, continued excellent environmental results were obtained and stable operation have been conducted. The sinter ratio in the blast furnace operation has been increased to 80 % from 60 %, leading to the large reduction in the production cost of hot metal.

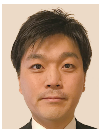
1. Introduction

Until now, the iron making process at JFE Steel West Japan Works (Fukuyama District; hereinafter, Fukuyama) was a production system comprising two sinter plants and three blast furnaces, and had depended on externally-sourced pellets for approximately 20 % of the main raw material for the blast furnaces. Considering these conditions, as well as the sharp increases in the prices of iron ore and coal of recent years, there was a heightened need for sintered ore from the viewpoint of reducing the production cost of hot metal, as sinter has more stable quality and is less expensive than pellets. Therefore, Fukuyama No. 3 Sinter Plant was constructed at Fukuyama during the period from April 2017 to December 2019 with the aim of increasing the sinter ratio[1)].

As a result of the enactment of the Act on Special Measures concerning Countermeasures against Dioxins (hereinafter, Dioxin Countermeasures Act) in 1999, more stringent environmental restrictions were applied to newly-constructed sinter plants, and in particular, selection of the specifications of environmental equipment became the most critical point in the construction of sinter plants in Japan. At No. 3 Sinter Plant, a state-of-the-art sinter machine and exhausted gas treatment equipment manufactured by Primetals Technologies were adopted and DS (Data Science) developed in-house by JFE Steel were introduced in order to reduce environmental loads and ensure stable operation during sinter production. **Photo 1** shows the condition of operation at the end of December 2019. To date, No. 3 Sinter Plant has continued to maintain excellent environmental performance and stable operation using these equipment and technologies. At the same time, the sinter ratio in blast furnace operation has increased from the conventional level of 60 % to 80 %, resulting in a substantial reduction in the production cost of hot metal. This report describes the construction of No. 3

† Originally published in *JFE GIHO* No. 49 (Feb. 2022), p. 74–79


[*1] Manager,
Sinter Plant,
Ironmaking Dept.,
West Japan Works (Fukuyama),
JFE Steel


[*2] Dr. Science,
Senior Researcher Manager,
Cyber-Physical System Research & Development Dept.,
Steel Res. Lab.,
JFE Steel

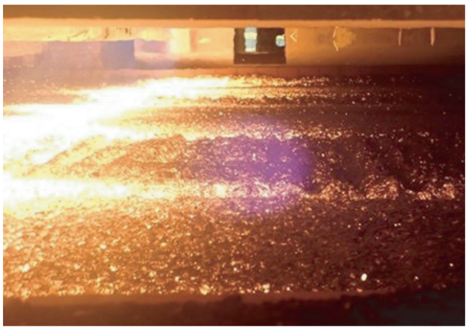

[*3] Staff Assistant Manager,
Plant Control Technology Sec.,
Plant Control Dept.,
West Japan Works (Fukuyama),
JFE Steel


[*4] Assistant Manager, Sinter Plant, Ironmaking Dept.,
West Japan Works (Fukuyama) (currently,
Staff Deputy Manager,
Advanced Reduction Process Development Dept.),
JFE Steel


[*5] Manager,
Ironmaking Technology Sec.,
Ironmaking Dept.,
East Japan Works (Keihin),
JFE Steel


[*6] Staff General Manager,
Carbon Recycling Development Dept.,
JFE Steel

(a) Appearance of No.3 SP building



(b) Ignition of sintering bed surface

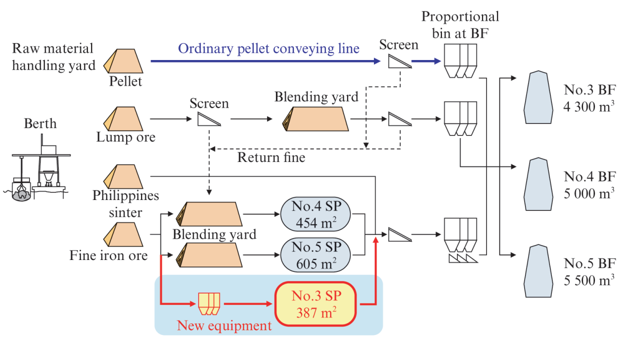
Photo 1 Appearance of No.3 SP starting operation in December 2019

Sinter Plant, which was the first newly-constructed sinter plant in JFE Steel in 43 years, and the application of DS technology, which has made an important contribution to stable operation of the plant.

2. Overview of Construction

2.1 Setting of Production Capacity

Figure 1 shows the raw material handling flow in the iron making process at Fukuyama. Conventionally, the sinter machines at Fukuyama comprised 2 comparatively large-scale sinter machines, No. 4 Sinter Plant (operation start: 1971, suction area: 454 m^2) and No. 5 Sinter Plant (1973, 605 m^2), while the blast furnace system consisted of 3 large-scale blast furnaces, No. 3 Blast Furnace (operation start: 2011, inner volume: 4 300 m^3), No. 4 Blast Furnace (2006, 5 000 m^3) and No. 5 Blast Furnace (2005, 5 500 m^3). Therefore, in the balance of sinter supply and demand, the sinter production capacity was always insufficient for the consumption by the blast furnaces, and in an average year, the sinter ratio had been limited to around 60 %. Although the production rate differs from year to year, in the actual results for the past 10 years, use of externally-sourced pellets was 1.5 to 3.0 million t/y, which was a large factor in deterioration of the production cost of hot metal. Therefore, in order to increase the sinter ratio of the blast furnaces so as to reduce production costs while also enabling a more flexible response to changes in the production rate due to economic conditions, a production capacity of 3.0 to 4.0 million t/y of lump sinter was assumed for the new No. 3 Sinter Plant, and the suction area of the sinter machine was set at 387 m^2.



	Proportion of sinter at BF (%)	Proportion of pellet at BF (%)	Proportion of lump ore at BF (%)	Total (%)
Ordinary	60	20	20	100
After No.3 SP construction	80	0	20	100

Fig. 1 Raw material handling flow of iron making process at Fukuyama works

2.2 Equipment Configuration

Figure 2 shows the outline of the equipment at No. 3 Sinter Plant. This was a full plant construction project responding to the environmental restrictions under the current law, and was the first such project in Japan since enactment of the above-mentioned Dioxin Countermeasures Act. Before enactment of the new law, a maximum value of 1.0 ng-TEQ/Nm^3 of dioxins (DXN) in the exhausted gas had been permissible, but because No. 3 Sinter Plant was constructed after enactment, operation at 0.1 ng-TEQ/Nm^3 was required. The DXN countermeasures for waste incineration facilities in Japan up to the time[2, 3] were exhausted gas quenching (requiring installation of a boiler, etc.) to prevent de-novo synthesis of DXN, or thoroughgoing dedusting, focusing on the characteristic that DXN is discharged adhering to the dust in the exhausted gas. However, the temperature of the exhausted gas in the sintering operation is not a high temperature of 800 to

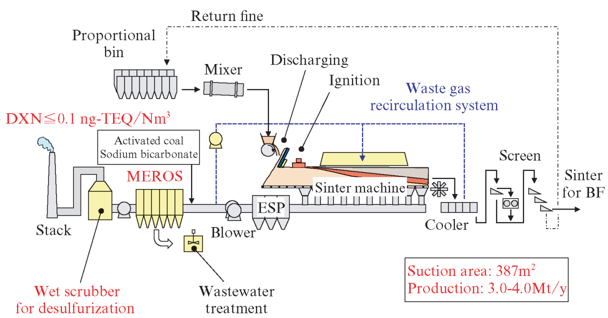


Fig. 2 Outline of No.3 SP equipment

900°C like that in the waste incineration process, but a low temperature of around 100 to 120°C, or about 300 to 400°C even near the end of the sinter machine, where the temperature is highest. This means that exhausted gas quenching of the type used in waste incineration facilities is not suitable for sinter machines. Therefore, in the new No. 3 Sinter Plant, a MEROS (Maximized Emission Reduction of Sintering) bag filter-type exhausted gas treatment system manufactured by Primetals Technologies was adopted[4, 5], with an aim to DXN reduction by thorough dedusting. The exhausted gas treatment performed by MEROS is not simply dedusting by the bag filter, but is a simultaneous dedusting, dedioxination and desulfurization process using combined injection of a dedioxination agent (activated coal) and a desulfurization agent (sodium bicarbonate). To enable more complete desulfurization at No. 3 Sinter Plant, magnesium hydroxide type desulfurization equipment was also introduced, and desulfurization is carried in a two-stage process with the MEROS system. In addition, a waste gas recirculation system manufactured by the same Primetals Technologies was introduced[4] as part of a specialized equipment configuration for reduction of environmental loads during sinter production which includes effective utilization of the sensible heat and CO gas contained in the exhausted gas from the sintering process, and aggressive reduction of the cost of exhausted gas treatment by reducing the amount of exhausted gas.

2.3 Construction Schedule

Figure 3 shows the construction schedule of No. 3 Sinter Plant. The new plant was constructed on the site of the former No. 3 Sinter Plant, which was in operation until 1982. Construction began after first removing the remaining equipment of the former No. 3 Sinter Plant (proportional bin, drum mixer, sinter plant building, screen building, electrostatic precipitator, main blower, etc.), and foundation construction began in November 2017. From June 2018, the main facilities, consisting of the sinter plant building, stack, proportional bin, various types of conveyors, screens, the sinter machine, and the exhausted gas treatment equipment, etc., were installed successively in parallel, and the main machinery installation and electrical wiring works were completed at the end of November 2019.

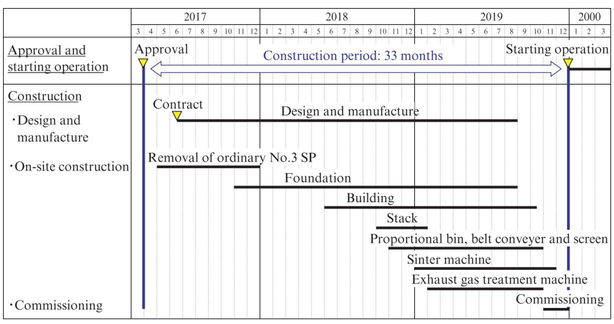


Fig. 3 Schedule of Fukuyama No.3 SP construction

Independent test run of the various equipment was carried out from November 2019, followed by sequential test run of all equipment from the belt conveyors in the raw material yard to the sinter screen in December 2019, and the first production of sinter was achieved on December 28, 2019. Various environmental measurements (exhausted gas volume, SO_X, NO_X, dust, dioxins, etc.) were conducted immediately after the start of operation, and work by 4 groups of operators in 8-hour shift started on January 2, 2020 with a trouble-free transition to 24-hour continuous operation.

3. Introduction of DS Technologies

3.1 Strengthening of Sensing

At No. 3 Sinter Plant, sensing was strengthened by introducing diverse types of measuring instruments as a state-of-the-art sinter machine. Technologies that can recognize the various phenomena which occur in the sintering process with high accuracy are necessary and indispensable for realizing the concept of CPS (Cyber Physical System) in a concrete form. As one DS technology, this chapter explains the equipment anomaly-sign detection system J-dscom™ (JFE detecting anomaly signs and color mapping system)[6]. Prevention of anomalies is an important issue because anomalies in the equipment or operation have a serious effect on productivity and quality. In addition to the process variables and manipulated variables collected by way of the DCS (Distributed Control System), No. 3 Sinter Plant was designed so that vibration and temperature data for many important units of equipment can also be measured by introducing a CMS (Condition Monitoring System) for the main purpose of equipment anomaly detection. J-dscom was introduced to enable unified control of this large volume of data and achieve equipment anomaly detection based on CBM (Condition Based Maintenance). Here, the datasets handled by J-dscom at No. 3 Sinter Plant are shown in **Table 1**.

3.2 Equipment Anomaly-Sign Detection System: J-dscom™

The distinctive feature of the J-dscom introduced in No. 3 Sinter Plant is the fact that this system collects data from both the DCS/PLC (Programmable Logic Controller) system and the CMS system. **Figure 4** shows an outline of the system configuration. Operation data and control data are collected at a rate of 2 000 points per second from the GW (Gate Way) con-

Table 1 Summary of data set acquired in J-dscom™

Source	Type	Number
DCS	Process variable	1 177
	Setting value	56
	Manipulated variable	55
	Others	76
PLC	Logic signal	541
CMS	Accelerometer	267
	Thermometer	66
	Level gauge	30

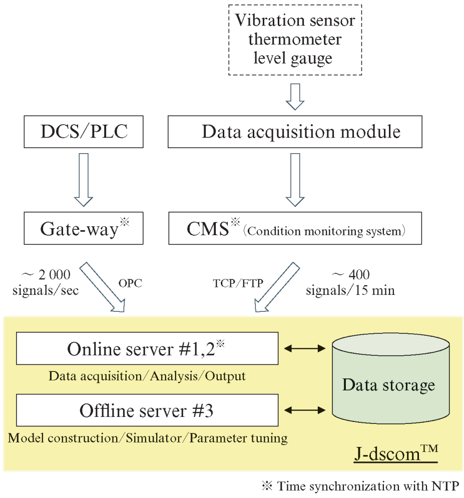


Fig. 4 System configuration of J-dscom™ at Fukuyama No.3 SP

necting the DCS and PLC. On the other hand, data from vibrometers, thermometers, oil level gauges, and other sensors at approximately 400 points, which were installed for equipment anomaly detection, are collected via the CMS in a 15-minute cycle. To simultaneously handle these two types of data, which have different collection paths and sensing cycles, correction of the system clocks of the respective system is essential. Therefore, the synchronicity of the total system is maintained by constantly performing time synchronization between the GW, J-dscom and the CMS using NTP (Network Time Protocol). This enables filtering of the equipment anomaly detection data collected by the CMS corresponding to the operating conditions and equipment setpoint values, and as a result, the S/N ratio (Signal-to-Noise ratio) of diagnosis has improved. The hardware configuration of J-dscom consists of a 3-computer environment and 1-file storage unit. Stable system response is secured by separating processing functions with a high computation cost, such as modeling, from the online environment. As the storage location for historical data, the file storage unit was also implemented as an independent environment, considering possible specification changes in the future, such as capacity expansion, distributed data management and the like.

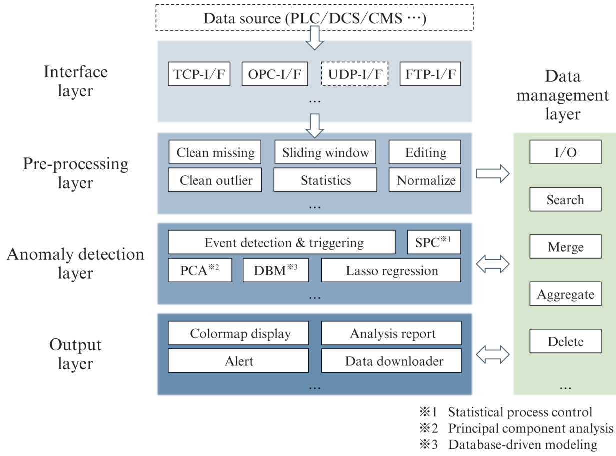


Fig. 5 Software architecture of J-dscom™ at Fukuyama No.3 SP

Next, **Fig. 5** shows the software configuration of the J-dscom in No. 3 Sinter Plant. In applying J-dscom to the sintering process, particular attention was given to improving data processing (preprocessing). Since the sintering process is a severe measurement environment, cases where correct measurement values cannot be obtained were foreseen, as errors may occur in the sensor data due to external disturbances such as adhering dust, corrosion, water vapor, etc., even when the sensors show normal values at a certain point in time. To enable correction of measurement errors on the software side even under these conditions, processing such as cleaning of missing data, smoothing using a sliding-window can also be performed by setting changes of the system. The configuration also makes it possible to combine computations of pairs of data and add the result as new data, and to freely perform processing of features that are consistent with the physical background. As output formats for the results of anomaly detection, diverse functions such as trend management by colormaps that enable efficient multi-point monitoring, warning notifications by the screen, alert sounds and email, automatic creation of anomaly reports and data downloading were implemented in the J-dscom at No. 3 Sinter Plant.

3.3 Anomaly Detection Methods

Multiple anomaly detection methods have been implemented in the J-dscom at No. 3 Sinter Plant, corresponding to the scale of the data which is the target of monitoring. For example, SPC (Statistical Process Control)[7] is used in anomaly detection of relatively simple types of data, such as the vibration levels of various motors and the temperature of conveyor bear-

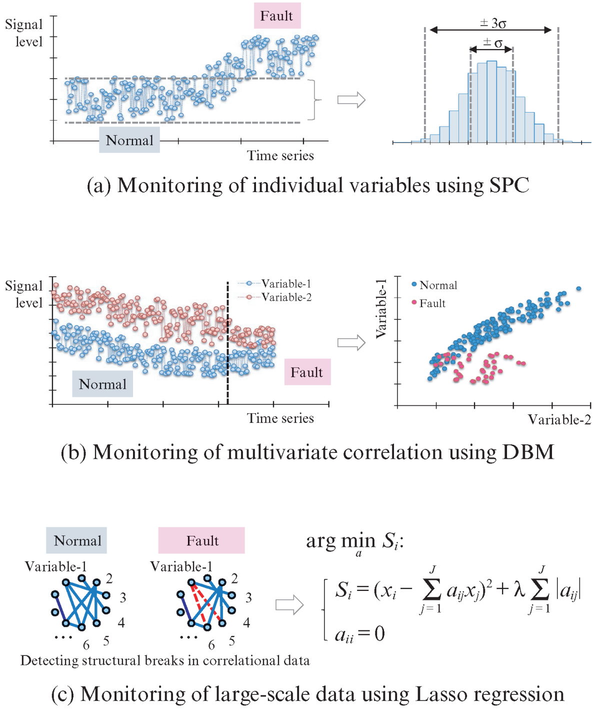


Fig. 6 Several application of anomaly detection methods according to the scale of data to be analyzed

ings, as shown in **Fig. 6** (a). In this case, the threshold can be set statistically by using statistical values (average, standard deviation) obtained from the normal data distribution.

Next, when the target is equipment with multiple data showing interconnected change, it is possible to apply monitoring of the multivariate correlation by using a DBM (Data Base Model), as shown in Fig. 6 (b). In anomaly detection by DBM, normal results from the past are registered in a database in advance, and when measured values for the judgment target are acquired, the difference between the data for the judgment target and the normal data stored in the database is calculated. This difference is monitored as the degree of deviation from the normal condition, and an anomaly is judged when this deviation exceeds a predetermined threshold. The object of monitoring by DBM is equipment in which a certain correlation exists, regardless of whether the correlation is linear or nonlinear.

In addition, an anomaly detection method based on Lasso regression[8)] has also been introduced, as shown in Fig. 6 (c), as a method for collectively monitoring datasets acquired from multiple equipment or processes as a whole. In the Lasso regression technique, very small regression coefficients become zero, so a broad reduction in unnecessary explanatory variables is possible. Predictive modelling is constructed by comparison with normal data prepared in advance, and when monitoring and judgment are performed for each individual variable, the prediction error defined as the difference between the prediction and newly-acquired actual values is calculated. Prediction error is small in cases where the data for the judgment target keep a normal relationship, but becomes large when this correlation breaks down, and in this case, an anomaly is detected. The degree of anomaly is controlled by calculating indexes based on the prediction error of the regression model for each variable.

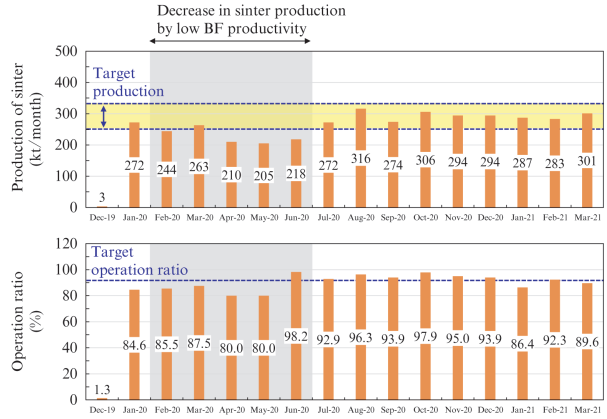


Fig. 7 Production and operation ratio after starting operation

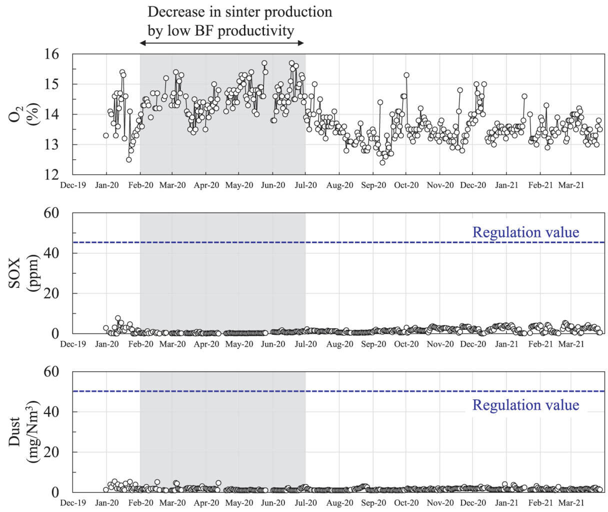


Fig. 8 Concentration of O_2, SOX and dust in exhaust gas at stack

4. Condition of Operation

4.1 Operating Condition

Figure 7 shows the production volume of sinter and the operation ratio after starting operation. Since continuous operation began in January of 2020, No. 3 Sinter Plant has continued to operate smoothly in spite of a temporary reduction of blast furnace productivity and adjustment of production accompanying banking of the Fukuyama No. 4 Blast Furnace due to the effects of the novel coronavirus. **Figure 8** shows the concentrations of O_2, SO_X and dust in the exhaust gas

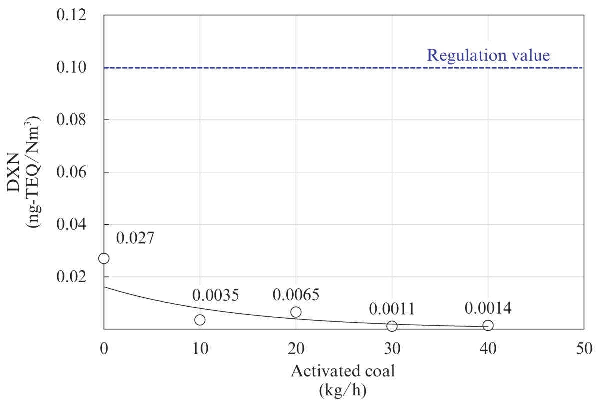


Fig. 9 Relationship between injection amount of activated coal to MEROS and concentration of DXN in exhaust gas at stack

at the stack. Since operation was possible with an exhaust gas O_2 concentration of approximately > 14 % under the Base case of normal production after July 2021, the condition of sinter machine leakage can be maintained low level to be satisfactory. The SO_X concentration at the stack was constantly approximately 1 to several ppm, confirming the high desulfurization effect of the 2-stage process using MEROS and magnesium hydroxide. The dust concentration was also constantly low, at around 1 to 2 mg/Nm^3, amply demonstrating the dedusting effect of the MEROS bag filter.

4.2 Measurement of DXN in Exhaust Gas

Figure 9 shows the relationship between the amount of activated coal injected in MEROS and the DXN concentration in the exhaust gas at the stack. Although the DXN concentration in the exhaust gas was the greatest challenge in the construction of the new No. 3 Sinter Plant, these results confirmed that the plant is operating as planned at a DXN concentration which does not exceed the standard value of 0.1 ng-TEQ/Nm^3 in the current law. Moreover, as can be seen in Fig. 9, operation at less than 0.1 ng-TEQ/Nm^3 is also fully possible, even without injection of activated coal in the MEROS process. However, the results confirmed that the DXN concentration at the stack tends to decrease further when the activated coal injection rate is increased.

4.3 Condition of Application of DS Technology

Installation of sensors at No. 3 Sinter Plant was completed in June of 2020, and equipment monitoring by J-dscom began from October after system tuning. As one example of equipment monitoring, **Fig. 10** shows an example of detection of a vibration anomaly of a motor bearing by the CMS installed at a belt conveyor. In this example, an intermittently increasing tendency was observed in the vibration values measured

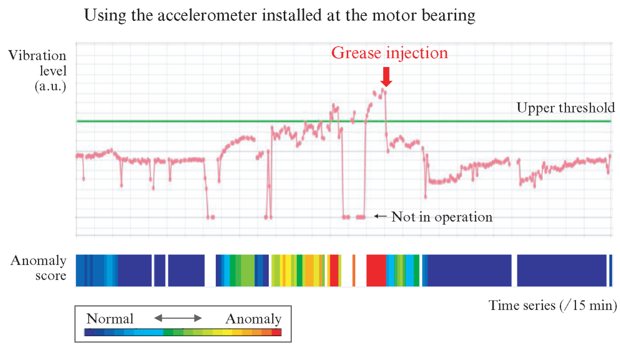


Fig. 10 Example of anomaly detection using vibration analysis of motor bearing

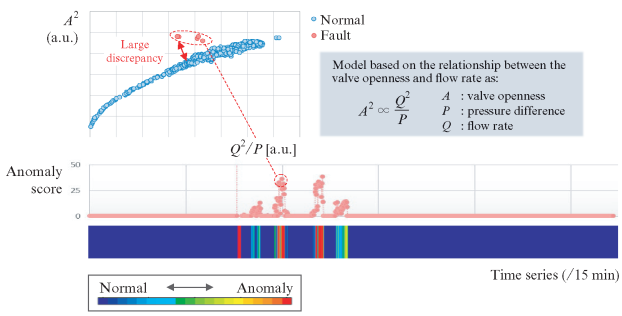


Fig. 11 Example of anomaly detection in the gas flow control of the ignition furnace

by an acceleration sensor. Because insufficient grease in the bearing could be found in a site inspection, the normal vibration value was restored by injecting additional grease. As illustrated by this example, it is possible to extract and evaluate only anomalous vibration values while the equipment is in operation by using the operating status signals of the target equipment collected by the PLC. As a result of an appropriate series of actions, a production decrease due to equipment trouble could be prevented in advance.

Figure 11 shows an example of anomaly detection of the model applied to gas flow control of the sinter machine ignition furnace. In this example, the in-furnace condition of the ignition furnace had deteriorated due to refractories falling off in the furnace, and changes had also occurred in the flow rate of the C-gas (coke oven gas) supplied to the ignition furnace. In anomaly detection of the gas flow rate using J-dscom, the model is implemented based on the physical relationship between the opening of C-gas flow control valve, the primary pressure (pressure in the main pipe supplied to the plant), the secondary pressure (pressure in the branched pipes serving individual burners) and C-gas flow rate. Data which deviated greatly from the response obtained in normal operation were measured in this example, showing that it is possible to detect anomalies as an increase in the anomaly score.

As shown in Fig. 10 and Fig. 11, it has become possible to prevent environmental anomalies and extended equipment trouble in advance by applying DS technologies using J-dscom. In the future, we plan to expand the targets of equipment anomaly-sign monitoring as necessary in order to further improve environmental performance and maintain stable operation.

5. Conclusion

At JFE Steel West Japan Works (Fukuyama District), operation of No. 3 Sinter Plant began at the end of December 2019. The new plant is equipped with a state-of-the-art sinter machine and exhausted gas treatment equipment, and DS (Data Science) technologies developed in-house by JFE Steel were also introduced. At present, the plant is continuing to achieve excellent environmental performance and stable operation, and a large reduction in the production cost of hot metal was also possible by increasing the sinter ratio in blast furnace operation from the conventional 60 % to 80 %.

Acknowledgement

For JFE Steel Corporation, the construction of the new Fukuyama No. 3 Sinter Plant described in this paper was the first full plant construction project in 43 years, since the construction of No. 1 Sinter Plant at East Japan Works (Keihin District). Even though no persons with experience in the construction of a full plant were available in JFE Steel, it was possible to proceed smoothly with the construction and startup of the new plant as planned thanks to the cooperation of the equipment manufacturers, beginning with Primetals Technologies, and many persons involved in construction at the site. We wish to take this opportunity to express our deep appreciation to all concerned.

References

1) JFE Steel. Production and Technology of Iron and Steel in Japan during 2020. Bulletin of the Iron and Steel Institute of Japan. 2021, vol. 26, no. 5, p. 269.
2) Nagata, K. State-of-the-art of PCDD/PCDF Emission Control for Municipal Waste Incinerators. Waste Management Research. 1992, vol. 3, no. 3, p. 217–237.
3) Ando, R.; Maeda, Y.; Nishimura, R. About the Performance Examination of the Dry Process Effluent Gas Disposal of Effluent Gas System Generated from a Chinese City Incinerator. Journal of Environmental Conservation Engineering. 2009, vol. 38, no. 2, p. 126–130.
4) Fleischanderl, A.; Böberl, M.; Steinwandter, A. Steel Plants Are Greener Than You Might Think. Bulletin of the Iron and Steel Institute of Japan. 2019, vol. 24, no. 12, p. 802–810.
5) Fleischanderl, A.; Steinwandter, A.; Neuhold, R.; Plattner, T.; Mizuki, H. MEROS®—Introduction of dry gas cleaning technology. Industrial Machinery. 2020, no. 833, p. 22–25.
6) Hirata, T.; Hachiya, Y.; Suzuki, N. Anomaly-Signs Detection Techniques of Steel Making Facilities Utilizing Data Science. JFE Technical Report. 2021, no. 26, p. 15–20.
7) Oakland, J. Statistical Process Control. 6th ed., Routledge, 2007, 458p.
8) Tibshirani, R. Regression Shrinkage and Selection via the Lasso. Journal of the Royal Statistical Society. Series B (Methodological), 1996, vol. 58, issue. 1, p. 267–288.