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Efficient Design, Inspection and Replacement of Equipment by Utilizing 3D Shape Measurement Technology

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Abstract:

Technologies relating to design, inspection, and replacement efficiency of equipment has been developed by measuring three-dimensional shape of equipment utilizing the latest 3D Shape measurement technology. Through the use of 3D measurement technology to improve efficiency of partial replacement work at the bottom of the converter furnace, to improve efficiency of inspection and replacement of radiant tubes in the furnace, and to improve efficiency of piping design work by combining 3D technology, efficient design, inspection and replacement of equipment was archived. Some selected technologies have been currently applied to plant engineering business of JFE Steel Group.

1. Introduction

The JFE Steel Group has developed state-of-the-art 3-dimensional (3D) measurement technologies to achieve higher efficiency in the design, inspection and replacement of equipment, piping, etc. Use of 3D measurement technologies in various fields began with the advent of the 3D laser scanner, which enabled high speed collection of large volumes of highly accurate 3D information[1–4]. When 3D laser scanners began to appear, modeling was a labor-intensive process, and this was an obstacle to popularization. However, in the past several years, 3D laser scanners have gained wide acceptance owing to rapid progress in modeling technologies utilizing automatic shape recognition, higher point density and functional improvement of CAD software, which have made it possible to perform design reviews and interference checks without modeling, together with dramatic improvement in the accuracy of digital images and more sophisticated processing software. In 3D laser scanner technology, the 3-dimensional coordinates of the measurement target are acquired by polarizing a laser beam with a mirror, measuring the distance between the object of measurement and sensor by the return time of a laser pulse, and simultaneously measuring the direction of laser beam emission. Measurement methods can be classified into two types, the time-of-flight (TOF) method, in which the distance is calculated from the time required for a laser beam reflected by the measurement target to return to the sensor and the angle is calculated from the angle of the laser travel direction, and the phase shift method, in which the measured distance is calculated from the phase difference (interference waves) of several laser wavelengths[5]. The TOF method is suitable for measurement over long distances and measurement of large areas, while the phase shift method has the advantage of rapid acquisition of a large volume of point cloud data. It is important to use these two methods appropriately depending on the purpose.

This paper introduces examples of development and application of efficient design, inspection and replacement techniques utilizing the latest 3D measurement technologies.

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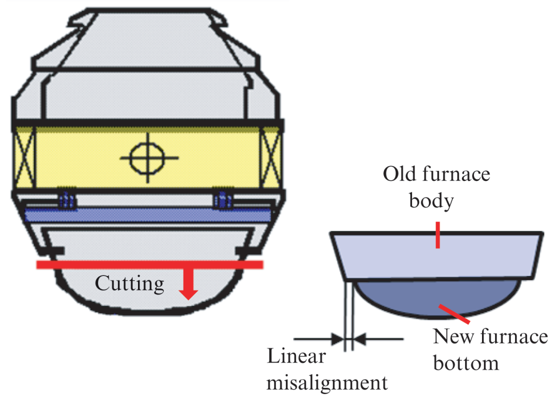


Fig. 1 Outline of partial update of converter furnace bottom

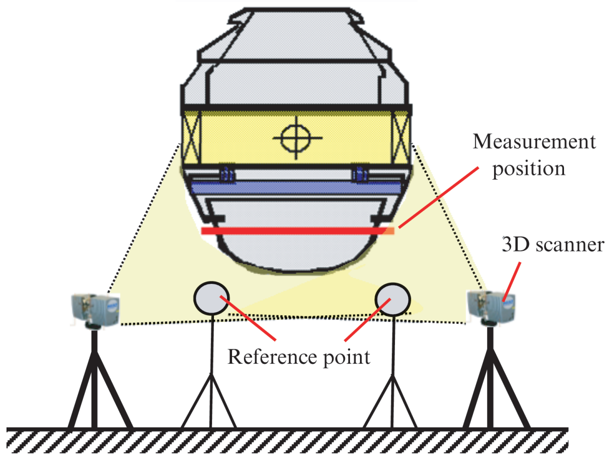


Fig. 2 Outline of 3D shape measurements from multiple places

2. Efficient Work of Partial Replacement of Converter Furnace Bottom Utilizing 3D Shape Measurement Technology

In partial replacement of a converter furnace bottom, as shown in **Fig. 1**, it is necessary to cut the bottom part of the old furnace and join the new bottom to the old furnace so that it matches the swelling of the old furnace body. The following introduces a development example in which the construction period in partial replacement of a converter furnace bottom was shortened by "building in" the necessary shape in the shop, while limiting the misalignment of the welded joint faces of no more 40 mm, by utilizing 3D shape measurement technology. Since this work was performed in advance, it was possible to omit the time normally required for additional joint face processing at the site.

2.1 Problem in Partial Replacement Construction

With the conventional measurement method, the inner diameter of the converter near the cutting line was measured at a total of 16 points at intervals of 22.5° with a general-purpose laser range finder, and as a result, it was found that expansion reached a maximum of more than 240 mm in comparison with the drawing dimensions. However, the measurement accuracy of laser range finders is not adequate when the furnace body is tilted.

2.2 Partial Replacement Work Utilizing 3D Shape Measurement Technology

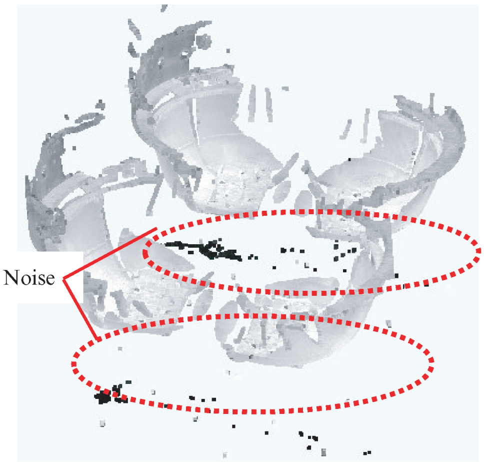
In order to build the necessary shape into the new furnace bottom so that it matched the expansion of the old furnace body with misalignment of the welded joint faces of no more than 40 mm, 3D scanners were used to make efficient, highly accurate measurements at the site. In these measurements, the furnace body shape around the full 360° circumference was measured at the position corresponding to the cutting plane of the old furnace body. As shown in **Fig. 2**, reference points were established and 3D shape measurements were performed from multiple places.

The 3D shape measurements were made at a speed of 120 000 points/s at each measurement place and required only about 1 min. Measurement noise reduction and approximate processing of lacking data were performed by applying smoothing image synthesis processing to the data measured from the four measurement places, as shown in **Fig. 3** (a), in order to construct a furnace body shape model of the 360° circumference, as shown in Fig. 3 (b).

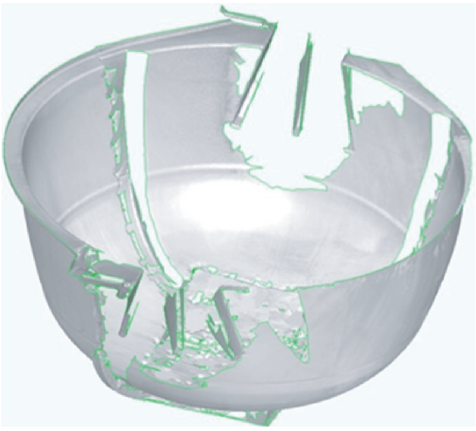
The shape of the old furnace body at the cutting plane was obtained from the constructed furnace body shape model. The new, perfectly-circular furnace bottom was then press-worked to a non-circular shape that matched the shape of the old furnace body, and the misalignment of the joint face with the old furnace body was corrected to a maximum of approximately 10 mm or less, as shown in **Fig. 4**. In addition to measurement of the 3D shape of the welding face after press working, the old furnace body was measured again during cutting, and the position that minimized misalignment with the joint face after press working was selected. As a result, it was possible to weld the joint of the old furnace body and new furnace bottom without additional processing of the joint faces at the site.

2.3 Summary

In a partial replacement of a converter furnace bottom, a technique for calculating the swelling at the cutting plane of the old furnace body was developed, in which 3D shape measurements were made from multiple locations around the furnace bottom of the old furnace body, and a 3D furnace body shape model was



(a) Measurement data from 4 places



(b) After smoothing image synthesis process

Fig. 3　Smoothing image synthesis using reference points

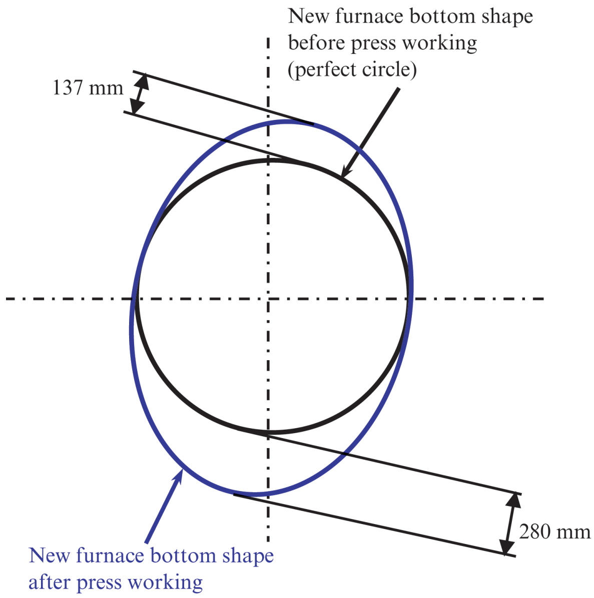


Fig. 4　Outline of press working at the new furnace bottom

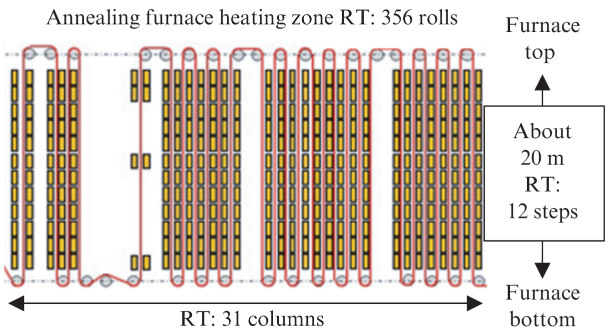


Fig. 5　RT layout of annealing furnace heating zone

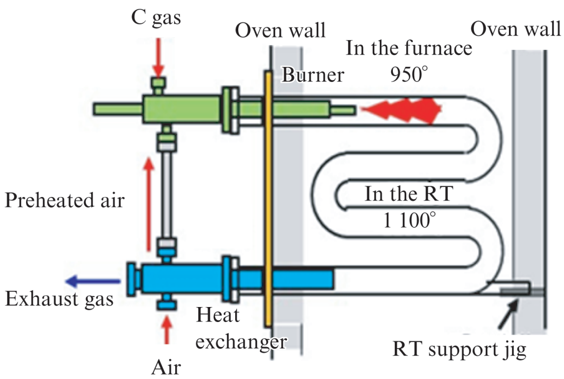


Fig. 6　RT combustion principle and temperature

then constructed by applying a smoothing image synthesis technology using reference points. By building in the proper shape of the new furnace bottom in the shop based on the calculation results, it was possible to reduce the misalignment of the welded joint faces at the site to less than the target of 40 mm. This eliminated the need for additional processing of the joint faces at the site, thereby shortening the work period for the partial replacement of the converter furnace bottom by 3.5 days. The JFE Steel Group is also performing commissioned measurement work and outside sales of plant engineering work utilizing the developed 3D shape measurement technology.

3. Efficient Inspection and Replacement of Furnace Radiant Tubes Utilizing 3D Measurement Technology

Remarkable thermal deformation occurs in the radiant tubes (hereinafter, RT) arranged in vertical annealing furnaces in cold strip mills because the RT are used under a high temperature environment. The RT layout and RT combustion principle and temperature are shown in **Fig. 5** and **Fig. 6**, respectively. Because a large number of RT are arranged in a narrow space in a high, dark area, precise inspections are not possible, and contact between steel strips and the RT can lead to operational trouble. Therefore, an inspection method that makes it possible to measure the deformation of all RT in a furnace was developed by using 3D measurement technology. By making it possible to grasp the actual amount of deformation of the RT, this technology supported a review of the RT maintenance control standard and contributed to efficient major repair planning and stable operation.

3.1 Problem of Conventional RT Maintenance

Conventional RT inspection work was performed mainly by visual inspection by personnel during major repairs, as shown in **Fig. 7**. Since the inspection results depended on photographs, memory, etc., the results were not quantitative and their reliability was low. In spite of the fact that the RT can only be replaced during major repairs, the selection of the RT to be replaced was based on unreliable inspection results and the use cycle (6 years), and it was not possible to establish replacement plans corresponding to the amount of deformation, which is the most important index.

3.2 RT Inspection and Replacement Utilizing 3D Measurement Technology

A technique for quantitative inspection of the deformation of all RT in a furnace, which had not been possible until now, was developed by utilizing the strong points of 3D measurement technology to the fullest possible extent.

In this measurement method, two-stage measurements are carried out at the furnace bottom level and furnace middle level, as shown in **Fig. 8**, and point cloud data are acquired for the top and bottom rolls as a standard in the analysis shown in **Fig. 9**. To confirm the reliability of this point cloud data, the drawing dimensions and analysis results for the distance between the rolls and the roll diameter were compared to confirm that accuracy was within ±3 mm and there were no problems. As a result, it is now possible to grasp the direction of RT deformation and the quantitative amount of deformation, as shown in Fig. 9, and formulate RT replacement plans corresponding to the amount of deformation. In addition, the mechanism of thermal deformation of the RT body over time was determined based on the results of multiple inspections, and the RT replacement standard was reviewed and a tougher RT body was proposed.

3.3 Summary

A quantitative inspection technique for the RT in furnaces was developed by utilizing 3D measurement technology. In the future, it is hoped that this technique will also be applied to similar equipment and used by customers in CBM (Condition Based Maintenance).

Trouble caused by contact with steel strips due to

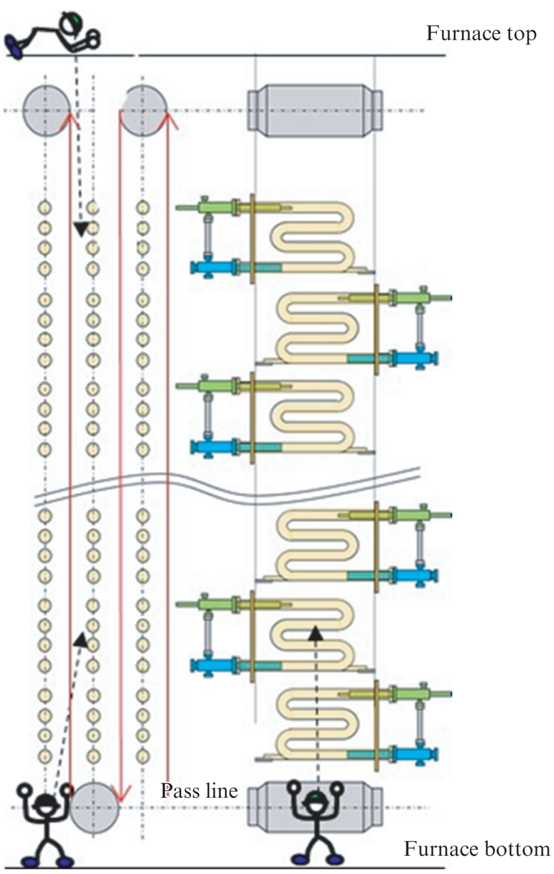


Fig. 7 Inner side and cross-sectional view of furnace

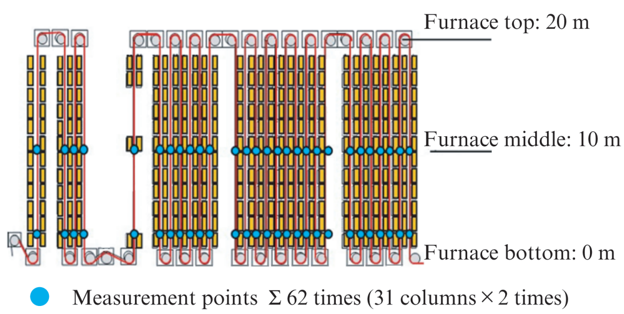


Fig. 8 3D measurement points

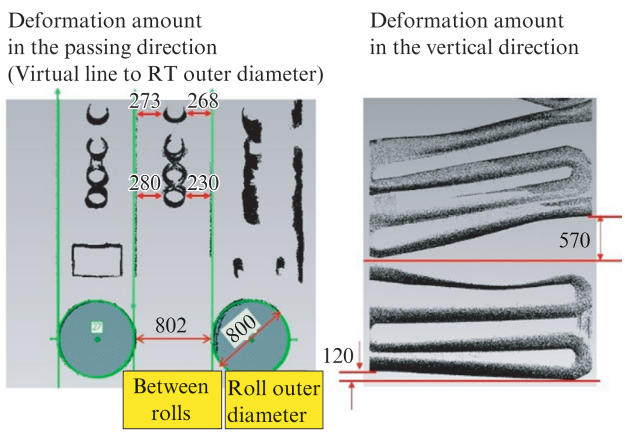


Fig. 9 Full view of 3D point cloud data (Unit: mm)

deformation of partition plates and furnace wall plates is an issue in furnace maintenance work. We intend to develop an inspection technique for the entire interior of the furnace, not limited to the RT, and utilize that technique to achieve even higher efficiency in maintenance work.

4. Efficient Piping Design Work by Combining 3D Technologies

The effectiveness of 3D scanners that scan and model equipment, etc. and point cloud editing software in improvement and repair of existing equipment in large steel works has been verified in recent years. Use of piping stress analysis software and other analytical software is also continuing to expand year by year. However, 3D software and analytical software had mainly been used independently of each other. Even if used in combination, efficient use was not possible, as it was necessary to perform the time-consuming task of modeling twice, i.e., by each of the two programs, due to the incompatibility of transferred data. In this development, we constructed a new system that makes it possible to transfer the data between the two by incorporating a 3D-CAD program as a converter between the 3D software and the analytical software. That system, which is introduced here, not only realizes efficient design work, but also can also be used as a basis for improving efficiency in construction as a whole, for example, by use in materials for meetings at the site.

4.1 Piping Design Work by Combining 3D Technologies

4.1.1 Efficient design work by new system

In this system, as shown in **Fig. 10**, AutoPIPE (hereinafter, AP) is used as the piping stress analysis software, GalaxyEYE (GE) is used as the data manipulation software for the 3D scanner point cloud data, and SolidWorks (SW) is used as the 3D-CAD software.

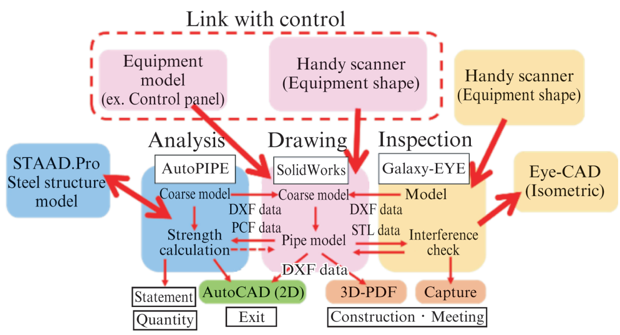


Fig. 10 New design model

Incorporating SW as the converter between AP and GE simplified data transfer, which had been difficult with the conventional approach. This made it possible to use AP in strength analysis of models created based on the site information measured by the 3D scanner, and to use GE to incorporate the model after analysis by AP in the site information and check for interference, contributing to a shortening of work time. Moreover, because the models prepared by the two software programs can be converted to drawings by SW, higher efficiency could also be realized in design work.

4.1.2 Higher efficiency in overall construction process by new system

In addition to preparation of drawings and study of strength and interference, it is also possible to convert the created models to 3D-PDF, as shown in **Fig. 11**, and to output visual materials for existing equipment, such as captures that include 3D scanner point cloud data.

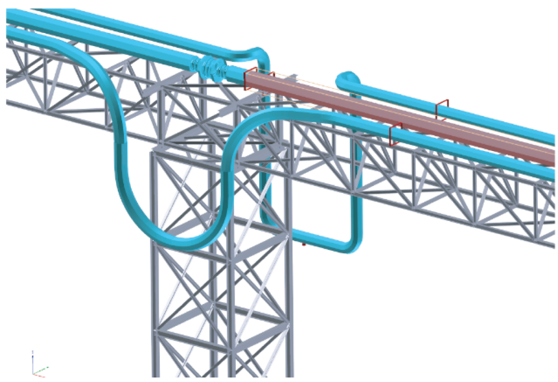


Fig. 11 3-dimensional PDF drawing

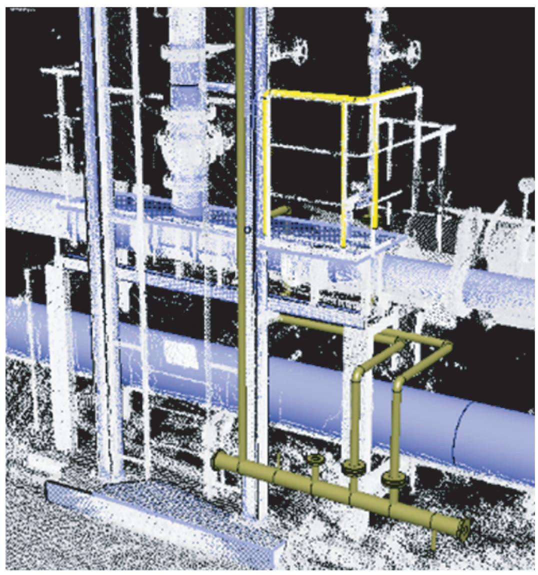


Fig. 12 3D scanner point cloud data capture of existing equipment

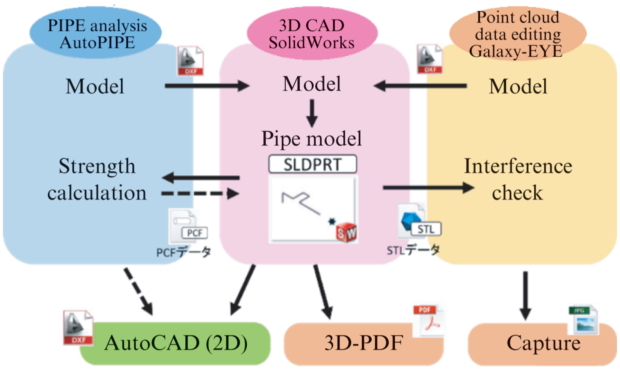


Fig. 13 Expansibility of system

As a result, it is now possible to confirm the relationship with existing equipment visually, as shown in **Fig. 12**. Because this does not require a special viewer such as CAD, etc., and viewing and 3D operations can be performed by anyone using general viewing software (Adobe Reader, etc.), it is considered effective for use as meeting materials, prevention of miscommunication in confirmation and coordination with the construction departments and construction companies, etc.

4.2 Summary

A review of the flow of piping installation work will be conducted using this system. Furthermore, as shown in **Fig. 13**, it is also possible to link this system with various other software, such as frame structure analysis software (STAAD.Pro) and EYE-CAD, etc. If those types of software are used, it is possible to improve accuracy and shorten working time in design work such as study of interference, study of strength, preparation of drawings, etc., in integrated mechanical and electrical construction work that includes piping, structures, wiring, etc., and to achieve higher efficiency in coordination by using visual materials. In the future, we intend to accumulate actual results of the use of this system and expand its range of applications.

5. Conclusion

This paper introduced examples of development and application in which the latest 3D measurement technologies were utilized to realize high efficiency in partial replacement of a converter furnace bottom and inspection and replacement of radiant tubes in a furnace, and a system combining different 3D technologies was used to improve work efficiency in piping design work. In the future, we intend to realize higher efficiency in the design, inspection and replacement of steel manufacturing equipment, and will also promote further development of these technologies to the plant engineering business of the JFE Steel Group.

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