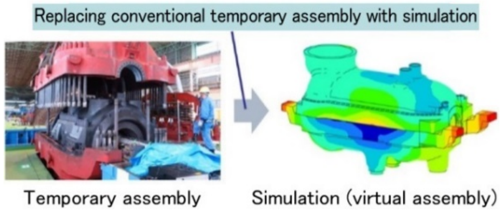
Virtual Assembly Technology Using 3D Laser Measurement and Finite Element Analysis Contributing to Shortening Periodic Inspection Period of Steam Turbines



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In periodic inspections of steam turbines, temporary assembly work to assemble the turbine is carried out to adjust the alignment and set the clearances between the stationary parts and the rotating parts to appropriate values in order to maintain turbine performance and prevent rubbing. From the viewpoint of efficient turbine operation, however, it is necessary for the temporary assembly work, which takes four to seven days for each turbine casing, to be eliminated.

This report presents a technology that shortens the periodic inspection period by replacing the temporary assembly work with virtual assembly that combines 3D laser measurement and finite element analysis.

1. Introduction

If the clearance between the stationary and rotating parts of a steam turbine is too large, the performance of the turbine will deteriorate and if the clearance is too small, the risk of rubbing will increase. In order to achieve both high performance and safety, it is important to adjust the clearance to an appropriate value. Components used in high-temperature and high-pressure environments, such as a turbine casing, may be creep-deformed and when the distorted casing is assembled, the internal components such as the blade ring move in the vertical direction from the position before assembly, which results in a clearance change. In periodic inspection, it is necessary to determine the clearance change during assembly and adjust the position of the blade ring in advance so that the centers of the rotor and blade ring after assembly match as shown in **Figure 1**.

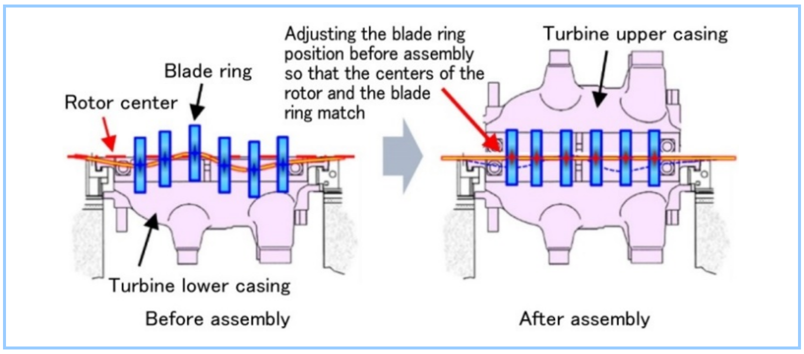

Figure 1 Movement of blade ring during assembly of turbine casing

As a method to determine the clearance change during the assembly of a turbine casing, the clearance change is measured by performing temporary assembly of the turbine casing and mandrel measurement shown in **Figure 2**. This method can measure the clearance change during the temporary assembly of a turbine casing by installing a measuring device called a mandrel, which allows measurement of the clearance change, instead of the rotor. However, since heat-tightening of bolts, etc., is needed, temporary assembly requires a process that takes four to seven days per turbine casing. For this reason, it has become necessary to abolish the temporary assembly work from the viewpoint of efficient turbine operation.

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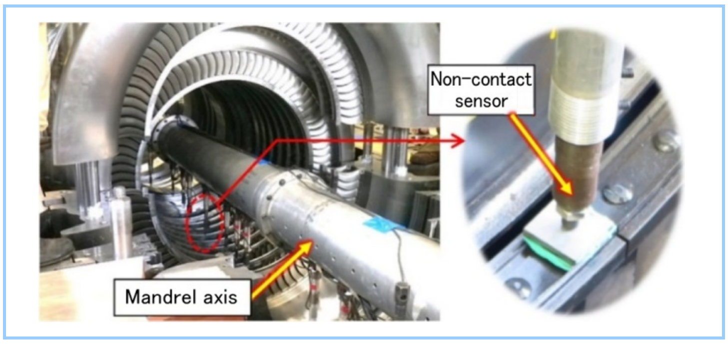

Figure 2 Measurement of clearance change by temporary assembly of turbine casing and mandrel measurement

This report presents a technology that predicts the clearance change without performing temporary assembly work by virtual assembly simulation that faithfully simulates turbine assembly. By applying this technology, a significant shortening of the periodic inspection process and extending of the operating periods of power plants are made possible as shown in **Figure 3**.

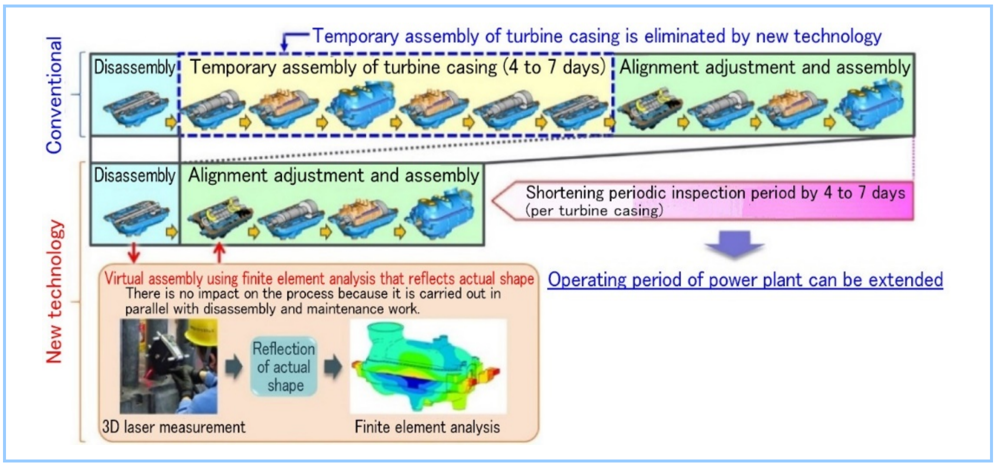

Figure 3 Shortening of periodic inspection period using virtual assembly technology

2. Virtual assembly technology

This chapter gives an outline of the virtual assembly technology according to the flowchart shown in **Figure 4**. This technology consists of three types of techniques: (1) acquisition of the shape of the turbine casing using 3D laser measurement ((a) to (b) in Figure 4), (2) reflection of the actual shape in the analysis mesh using data processing ((c) to (e) in Figure 4) and (3) estimation of the turbine casing deformation during assembly using finite element analysis ((f) in Figure 4). An overview of each technique is described below.

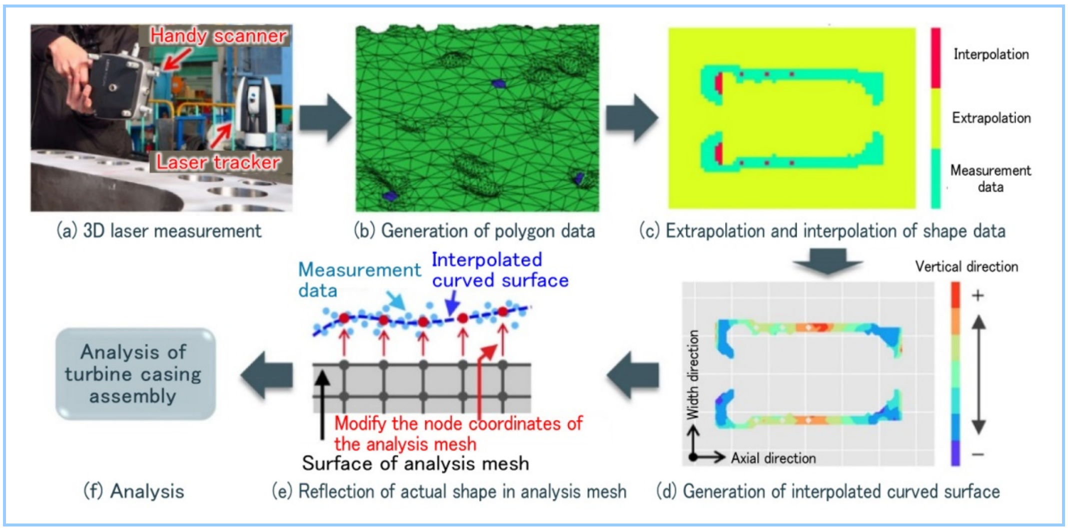

Figure 4 Flowchart of clearance change prediction using virtual assembly technology

(1) Acquisition of turbine casing shape using high-precision 3D laser measurement

3D laser measurement measures the horizontal flange surface shape of a turbine casing with a total length of about five meters with a high accuracy of about 50 micrometers by using a handy scanner and laser tracker that captures the scanner position shown in Figure 4 (a). **Figure 5** shows how the 3D laser measurement is performed. The measurer scans the horizontal flange surface with the handy scanner and confirms that there are no problems with the acquired shape data on the monitor. In laser measurement at an onsite periodic inspection, measurement noise caused by vibration of the plant building and data loss caused by obstacles such as studs may occur. However, this technique realizes accurate measurement due to the devised installation method of the laser tracker and the multi-position measurement. **Figure 6** is an example of the measured 3D shape data. This example is the data of a turbine casing for which the axially center part is deformed vertically upward. In areas where a stud exists, the laser of the laser tracker is blocked, so data loss is likely to occur inside or outside the flange surface. As a countermeasure, the position of the laser tracker is moved and measurements are taken from both the inside and outside of the flange surface to minimize data loss around studs. In this way, the measurement technique that acquires data with a small amount of noise without significant data loss realizes highly-accurate prediction of the clearance change.

Figure 5 3D laser measurement of turbine casing flange surface

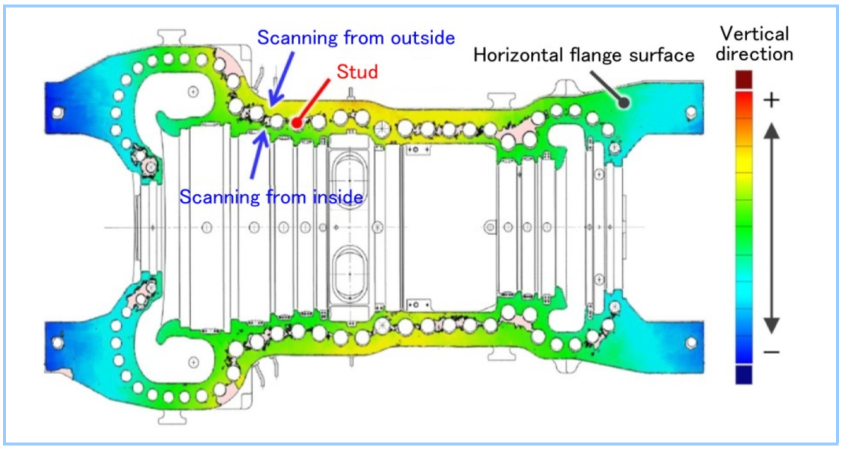

Figure 6 Example of 3D shape data of turbine casing flange surface

(2) Reflection of actual shape in analysis mesh using data processing

The shape data of the horizontal flange surface acquired by the 3D laser measurement is used to reflect the actual shape in the horizontal flange surface of the analysis mesh prepared in advance. By reflecting the actual shape only in the horizontal flange surface—which greatly affects the deformation behavior of the turbine casing—and using the shape of the design drawing for the other areas, the measurement and data processing time is reduced while maintaining the necessary prediction accuracy. In order to reflect the actual shape in the analysis mesh, it is necessary to create a continuous curved surface without data loss from the discrete shape data. Complete grid-like shape data without defects is generated by removing noise contained in the shape data and then filling in the missing data area through extrapolation or interpolation processing (Figure 4 (c)). Based on this data, the continuous interpolated curved surface shown in Figure 4 (d) is generated. Finally, by projecting the nodes on the horizontal flange surface of the analysis mesh onto the interpolated curved surface as shown in Figure 4 (e), conversion to an analysis mesh that the actual shape is reflected is performed. This series of processes is automated with a program and can be completed in about five minutes.

(3) Estimation of turbine casing deformation during assembly using finite element analysis

Finite element analysis that simulates the turbine casing assembly is performed using the analysis mesh that the actual shape is reflected. In the analysis, the support conditions that faithfully simulate the actual turbine as shown in **Figure 7** are set for the turbine casing and the rubbing conditions are given to the upper and lower horizontal flange surfaces. By applying the bolt tightening force, the deformation behavior during the assembly of the turbine casing is calculated. Based on the analysis result, the amount of movement of the blade ring, etc., from the original position before assembly is calculated and the clearance change is estimated. Then, the actual position of the blade ring is adjusted by using the estimated value of the clearance change so that the clearance after assembly becomes an appropriate value.

3D laser measurement (1) can be performed during disassembly of the turbine casing and the reflection of the actual shape (2) and finite element analysis (3) can be carried out in about one or two days. Therefore, it is possible to complete the estimation of the deformation of the turbine casing during its disassembly and maintenance work and the four to seven-day process required for the temporary assembly work can be shortened.

The above is a procedure for estimating the clearance change for one turbine casing. When the structure has an outer casing and an inner casing, the estimation can be made in the same way by adding together the clearance change of each component due to its deformation. In addition, for a relatively small part such as the blade ring, etc., the clearance change during the assembly thereof can be estimated by separately measuring the deformation during disassembly.

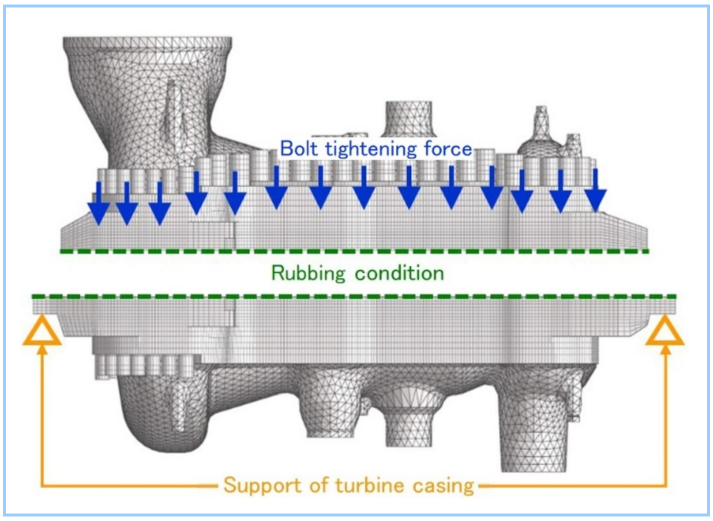

Figure 7 Condition of finite element analysis simulating turbine casing (outline)

3. Verification result on actual turbine

The developed virtual assembly technology was verified on actual turbines at two sites. **Figure 8** compares measured and predicted clearance changes at sites A and B. The measured value is the clearance change acquired by using mandrel measurement at the time when the turbine casing is actually temporarily assembled. In both cases, the predicted values resulting from the virtual assembly are almost the same as the measured values using temporary assembly and it was confirmed that the root mean square error (RMSE) was as small as about 0.1 mm. In particular, the analysis performed in the case of site B was a blind analysis in which simulations were carried out without knowing the measured values of the clearance change and achieved high accuracy under conditions close to those applied to actual periodic inspection, demonstrating the effectiveness of this technology.

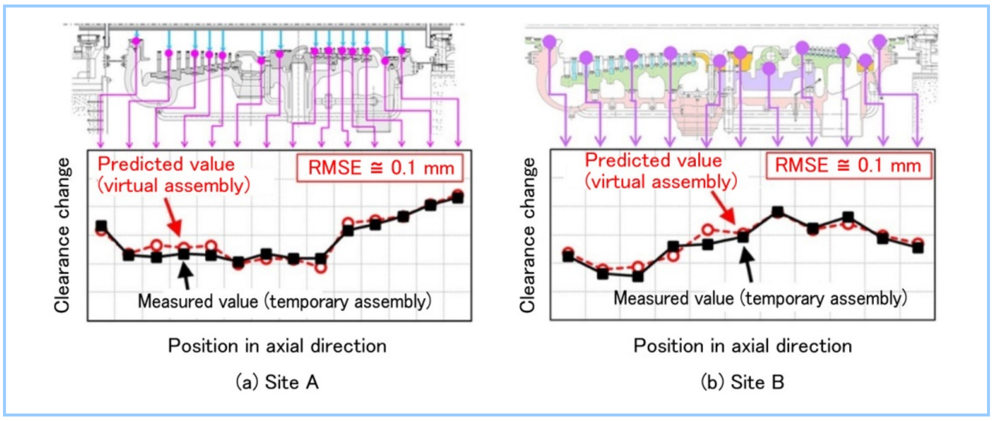

Figure 8 Result of verification using actual turbine

4. Conclusion

In order to contribute to the efficient operation of steam turbines, Mitsubishi Heavy Industries, Ltd. has developed a virtual assembly technology that shortens their periodic inspection period. It was confirmed using an actual turbine that it is possible to predict the clearance change during the assembly of a turbine casing with high accuracy by combining 3D laser measurement and finite element analysis to perform a simulation that takes into account the creep deformation of the turbine casing that occurs during operation. In the future, by promoting the application of this technology to periodic inspection and replacing the conventional temporary assembly work with virtual assembly in simulation, it is expected that the inspection process can be shortened by about four to seven days per turbine casing.