Performance Verification of X-ray CT for the Durability Assessment of Thermal Power Components

Background

It is very important to develop technologies in analytical durability assessment of thermal power high-temperature components based on the estimation of temperature distributions, which have severe impacts on the durability of the components (Fig.1). For the analytical assessment of the components, measurement and modeling of the geometries is indispensable. However, in order to measure the internal geometries of the cooled gas turbine blades by using an ordinary coordinate-measuring machine (CMM)[*1], slicing the blades is inevitable, and then the sample blades of the durability assessment are disabled from working in the turbine. Accordingly, non-destructive and rapid procedures in geometry measurement are demanded.

Objectives

In order to analytically assess the durability of gas turbine blades having complex geometry made with high density material, this study aims to evaluate performance of x-ray computed tomography (X-ray CT) in geometry measurement and modeling.

Principal Results

The performance of the industrial system of the X-ray CT (Table 1) was evaluated for a first stage rotor blade[*2] of a gas turbine.

1. Dimension errors in geometry modeling based on the non-destructive measurement

Blade geometry model (Fig.3) was reconstructed by stacking images of cross sections of the blade (Fig.2) taken with the X-ray CT system and outer dimensions of the blade geometry model was compared with point clouds measured by a contact-type CMM[*3]. As a result, the dimension error in the pressure side surface of the blade model was larger than in the suction side surface (Fig. 4), due to image noise, called artifact, resulting from attenuation of transmission X-ray. The mean error was around 0.1 mm in the measurement and modeling, and the error at a maximum was less than 0.5mm (Table 2).

2. Influence of the dimension errors upon estimation of blade temperature

The influences of the dimension errors upon calculation of the blade temperature were estimated under conditions in the gas turbine (Table 3 and Fig. 5). As a result, the errors in the blade temperature due to the dimension errors are less than 10K in either direction (Table 4) that is sufficiently small from the viewpoint of durability of the gas turbine blade.

Accordingly, it is clarified that the non-destructive geometry measurement by the X-ray CT is available for the analytical durability assessment of the gas turbine blade.

Future Developments

The methods of the numerical analysis will be advanced in order to contribute to rapidly assess the durability of the gas turbine blade. In addition, the analytical assessment based on the non-destructive geometry measurement will be further applied into the components in other thermal power equipments

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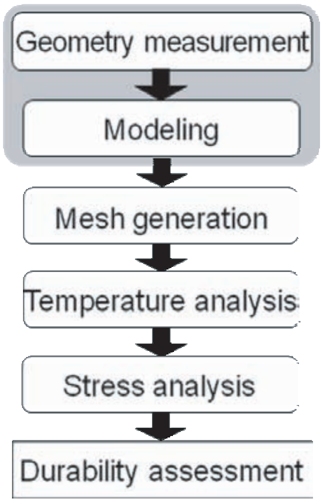
Reference

T. Takahashi, et al., 2009, “Performance Verification of X-ray CT to Apply on Non-destructive Geometry Measurement of a Thermal Power Component”, CRIEPI Report M08005 (in Japanese)

＊1：Contact-type or laser utilization equipments for measuring coordinates on surfaces of objects.
＊2：An ex-service blade having internal cooling passages without thermal barrier coating. The density of material is 8000kg/m^3.
＊3：The blade outer wall was employed for reference, because that makes the CMM able to accurately measure and, in principle, precision in measurement by the X-ray CT is independent of inner and outer structures.



: Subjects of the present research

Fig.1 Flow of analytical durability assessment

Table 1 Primary spec. of the industrial X-ray CT system

Output	450kV, 5mA (maximum)
Size of work	600mm height, ϕ300mm (maximum)
Imaging time	90sec. per image in Fig.2 Adjustable (25sec. per image at a minimum)

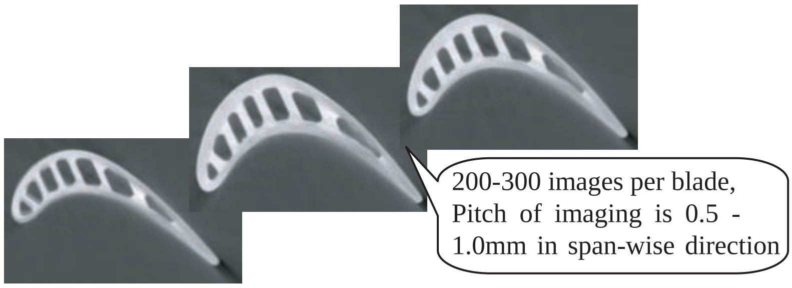
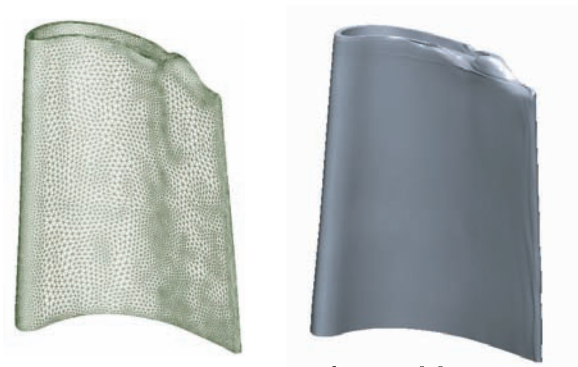


Fig.2 Images of cross sections of the gas turbine blade



Polygon model

Surface model in 3D-CAD Parametric surfaces based on polygon modeling

Fig.3 Geometry models based on cross sectional images

Non-destructive modeling is available by the X-ray CT

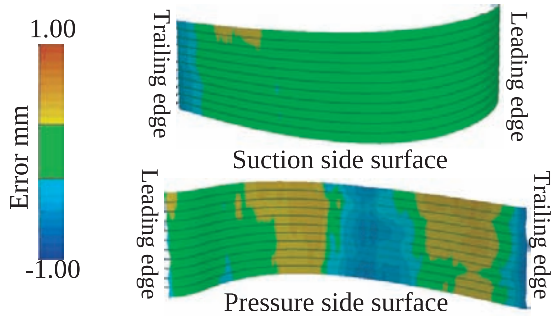


Fig.4 Distributions of dimension error
(Green color indicates errors less than 0.25mm)

Table 2 Dimension errors (absolute value)

mm	Suction side	Pressure side
Mean	0.053	0.127
Max.	0.342	0.480

Dimension errors in the model have been clarified

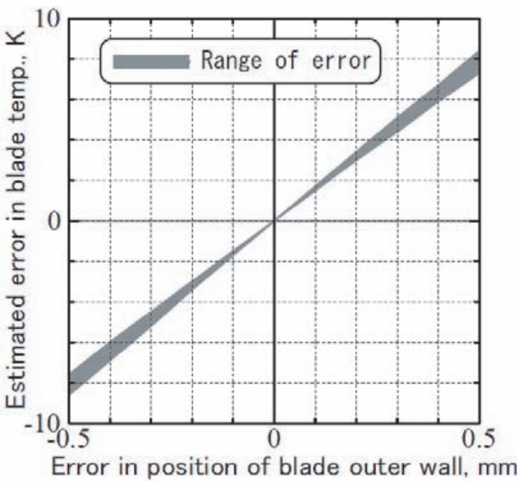


Fig.5 Influence of dimension error on blade temperature

Table 3 Conditions for estimating the blade temperature

Outer wall	Gas temp.	1561.15K
	Heat transfer coeff.	1500 W/(m^{2}K)
Substrate	Thermal conductivity	25 W/(mK)
	Thickness	3mm～5mm
Internal cooling	Air temp.	663.15K
	Heat transfer coeff.	2500 W/(m^{2}K)

Table 4 Estimated errors in calculations of the blade temperature

K	Suction side	Pressure side
Mean	±0.8～±0.9	±1.9～±2.2
Max.	+5.0～+5.8 −5.1～−5.9	+7.0～+8.1 −7.3～−8.3

The X-ray CT has sufficient precision in order to estimate the blade temperature subject to the durability