Development of Numerical Temperature Analysis using CFD for 1st Stage Rotor Blade of Gas Turbine for Power Generation

Background

The electric power companies in Japan are promoting introduction of combined cycle power plants with gas turbines(following GT) using liquefied natural gas for fuel as the main facility in thermal power generation. There are some merits in that operation of start up, shut down, and load adjustment are easy, thermal efficiency is high, exhaust gas is clean, and so on. On the other hand, because of an expensive maintenance cost for first stage rotor blade, this is a main component of GT, establishment of the technical criteria to judge how to maintain reasonably for users is expected. Therefore it is necessary to establish life evaluation technology with accuracy, and it is indispensable to predict temperature distribution of the first stage rotor blade. The temperature distribution is one of the main factors to influence life, and it is important that temperature distribution is grasped for life and reliability evaluation. However, it is hard technically to measure temperature distribution of blade actually in GT operation. Also because of complicated blade shape and heat transfer around the blade inside and outside surface, a highly precise estimation method of numerical analysis has not yet been developed.

Objectives

To develop a numerical analysis technique that can predict blade temperature distribution accurately and apply it to life evaluation, and to clarify three dimensional temperature distribution.

Principal Results

1. Construction of thermal conjugate analysis method

For 1100˚C class first stage rotor blade with multi-hall type cooling pass and 1300˚C class first stage rotor blade with serpentine cooling pass installed angled ribs, thermal conjugate analysis method is built to enable GT users who never have any design information. The numerical results are decided by convection heat transfer of combustion gas flow calculated by CFD (Computational Fluid Dynamics), blade structure materials heat conduction, and inner cooling heat transfer of blade (Fig.1).

2. Inspection of analysis precision

The high temperature area of blade surface by numerical simulation agreed well with the eroded area produced by high temperature oxidation in an actual blade (Fig.2). In addition, the numerical result also agreed with blade surface temperature estimated by materials organization of an actual blade. They were equal to or within 20˚C [*1], which is a precision goal in life evaluation.

3. Practical use of this numerical simulation technology

Parametric evaluations to blade temperature for unknown factors in GT operating condition, combustion gas flow temperature distribution or cooling air mass flow rate, were enabled by using the numerical simulation technique. In addition, three dimensional temperature distribution of the blade in time series of start up and shut down conditions which are indispensable for thermal fatigue damage evaluation were estimated.

To sum up, our intended objective to develop numerical analysis technique with high accuracy was achieved for GT blade installed cooling pass.

Future Developments

The technique will be expanded to the latest GT blade, which adopts the film cooling heat transfer.

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Reference

K. Watanabe, et.al. , 2005, “Development of numerical temperature analysis using CFD for 1st stage rotor blade of gas turbine for power generation”, Technical Report M01 (in Japanese)

＊1：Difference of 20˚C in operating temperature(about 850˚C) means creep rupture life change to twice or half, it has serious influence on accuracy of life estimation

Table 1 Comparison of temperature estimation technique for actual gas turbine blade

	Measurement		Estimation by change of metal organization		Numerical simulation
Technique	Thermocouples	Pyrometer	Growth of γ'*2 diameter	Growth of boundary diffusion layer	Thermal conduction analysis
Merit	High initial reliability	Non-contact measurement	Possible to estimate metal temperature of the blade at any point	Possible to estimate surface temperature distribution of blade	Possible to estimate the whole temperature distribution of blade
Demerit	● Short life ● Serious influence to other parts by destruction and scattering	Low accuracy because of no knowledge about physical properties for radiation	● Need to cut off blade ● Estimation only time averaged temperature for the blade		Difficult to set detail boundary conditions, e.g. heat transfer coefficient distribution on the surface

＊2: Granular intermetallic compound deposited in based metal Ni. It contributed to improve strength.

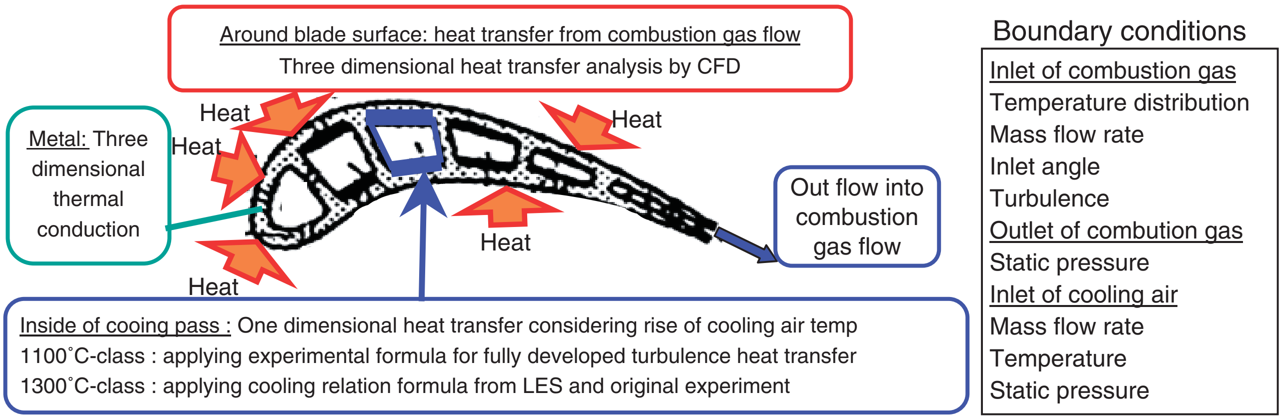

Fig.1 The concept of thermal conjugate analysis method

Thermal conjugate analysis method was built based on CFD and heat transfer experiments

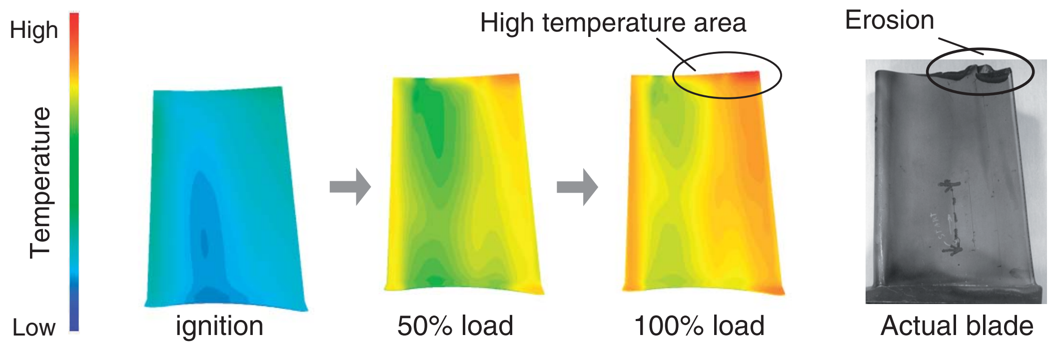

Fig.2 Temperature distribution of pressure side surface of blade in start up process and actual blade damage

Estimation of temperature distribution in a time series was enabled. High temperature area agreed well with damage area.

[Relevant papers]

- Toshihiko Takahashi, Kazunori Watanabe and Takeshi Takahashi, "Thermal Conjugate Analysis of a First Stage Blade in a Gas Turbine", ASME-Paper 2000-GT-251, 2000
- Toshihiko Takahashi, Kazunori Watanabe and Takeshi Takahashi, "Transient Analyses of Conjugate Heat Transfer of a First Stage Rotor Blade in Start-up and Shut-down", ASME-Paper 2001-GT-171, 2001
- Kazunori Watanabe, Toshihiko Takahashi, "Les Simulation and Experimental Measurement of Fully Developed Ribbed Channel Flow and Heat Transfer", ASME-Paper GT-2002-30203, 2002
- Toshihiko Takahashi, Kazunori Watanabe, "Large Eddy Simulation of Flow and Heat Transfer in a Rectangular Channel with Crossed Angled Ribs", ASME-Paper GT-2004-53673, 2004
- Toshihiko Takahashi, Kazunori Watanabe, "Conjugate Heat Transfer Analysis of a Rotor Blade with Rib-roughened Internal Cooling Passages", ASME-Paper GT-2005-68227, 2005