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Effect of thermal stress on creep lifetime for a gas turbine combustion liner

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ABSTRACT

The present study investigates the effect of thermal stress on the creep lifetime for a combustion liner in a gas turbine. For the calculation of thermal stress of a combustion liner, 3D-numerical analyses are performed using an FEM commercial code. Actual operating conditions and material properties are also applied for the realistic calculation. As a result, high thermal stress is locally induced in the inlet of the rib-roughened region of the whole combustion liner. That is attributed to the high temperature gradients formed from the large temperature differences between the hot spots and the surrounding low temperature regions. The result is in a good agreement with the actually damaged combustion liner. Moreover, the hot gas side of the inlet of the rib-roughened region appeared vulnerable to creep and the minimum creep lifetime is estimated to be approximately 26,900 h.

1. Introduction

It is evident that the turbine inlet temperature (TIT) and the compressor discharge pressure should be increased to improve the performance of a gas turbine. In modern gas turbine engines, TIT has been steadily increased, thus novel base materials (such as super alloys), thermal barrier coatings (TBC), and/or advanced cooling methods have been extensively applied to improve the durability and the reliability of the hot components of gas turbine.

As TIT is increased, hot components such as combustion liners, vanes, and blades should be protected from high temperature environment by using advanced cooling techniques. Especially, the gas turbine combustion liner is exposed to excessively high thermal load ($\sim$1750 K) due to direct interaction with extremely hot combustion gas. For combustion liner cooling, various cooling methods such as impinging jet cooling, film cooling, and internal passage cooling are generally applied. Such cooling methods are usually applied in a combined fashion to maximize the cooling performance [1–9].

Nevertheless, hot components of gas turbines are still vulnerable under harsh thermal conditions thereby suffering from local thermal cracks and structural failure. Since the thermal stress is mainly induced by the temperature differences along the substrate which leads to the critical thermal damage of the hot components, there is a critical requirement to predict the thermal stress distributions of hot components under an actual operating condition [10–12].

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Nomenclature

E	Young's modulus
h	convective heat transfer coefficients, $q''/(T_w - T_m)$
k	thermal conductivity
p	Larson–Miller parameter
t	creep lifetime
T_w	wall temperature
ΔT	temperature difference
Greek symbols	
α	thermal expansion coefficient
ε_v	von Mises strain
ν	Poisson's ratio
σ	stress
σ_v	von Mises equivalent stress

Under this circumstance, most of the studies on the gas turbine hot components are mainly focused on fluid dynamics or heat transfer measurement/enhancement. Likewise, for the combustion systems, there are also numerous studies such as combustion mechanism, combustion gas flow, and heat transfer in combustors [13–15]. There have been some efforts to predict failure and lifetime in combustors, but only for the local part of component or segments in archival journal papers [16,17].

In this study, therefore, we focus on the thermal failure analysis and lifetime prediction of the whole gas turbine combustion liner. For the analysis and prediction, we calculated the thermal stress of the whole combustion liner under the actual base-load operating conditions with real conditions and material properties. With this calculated result, we also predict the creep lifetime of whole combustion liner using Larson–Miller parameter.

2. Research methods

The objective of the present study is to analyze the thermal stress and to predict the lifetime on a whole combustion liner. First, FEM analysis was performed to figure out the thermal stress distributions on the combustion liner. Then, the creep lifetime prediction was conducted for the combustion liner during the steady base-load operation using the calculated thermal stress results.

2.1. Geometry and cooling method

The dry low NOx combustion liner that is typically applied to land-based gas turbine was modeled. A single combustion liner consists of six premixed burners and it is composed of the several additional components such as flow sleeve, combustion liner, impinging sleeve, and transition piece [10,12]. The impinging and flow sleeves surround the transition piece and combustion liner, and this combination creates a flow channel between the sleeves and combustion liner and transition piece for forced convective cooling.

It should be noted that this combustion liner mainly adopts impinging jet cooling and rib-roughened passage cooling, instead of film cooling for lean premixed combustion. As Fig. 1 indicates, the combustion liner falls into three parts such

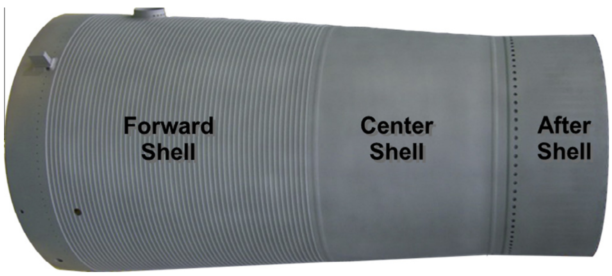

Fig. 1. Geometry of target combustion liner.