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Estimation of Gas Turbine Blades Cooling Efficiency

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Abstract

This paper outlines the results of the evaluation of the most thermally stressed gas turbine elements, first stage power turbine blades, cooling efficiency. The calculations were implemented using a numerical simulation based on the Finite Element Method. The volume average temperature of the blade and the coefficient of heat transfer from the cooling medium to the cooling channel wall were chosen as the cooling efficiency criteria. A comparison of steam and air used as coolants was done, and the calculations were performed using ANSYS Fluent software.

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Keywords: gas turbine blade; cooling efficiency; CFD; thermal analysis; thermal stresses.

1. Introduction

There is a continuous desire to increase the thermal efficiency of gas turbines, which is realized mainly by increasing the turbine inlet temperature of the gases [1]. At the same time, gas temperature growth rate exceeds that of the heat resistance of alloys used in metallurgy [2]. Modern gas turbines operate at a turbine inlet temperature of more than 1600^0C [3]. In order to provide the possibility of high temperature elements operation at such high parameters, it is necessary to use thermal barrier coatings [4,5] and advanced cooling systems [6].

Experimental tests to estimate the cooling efficiency of gas turbine elements are complicated. In recent years, it is more frequently used to perform the computer modeling of the thermal state of the cooling elements based on the finite element method. Whilst such an approach is significantly less expensive, the results have a good compliance with the experimental data.

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This paper evaluates the thermal state of the most stressed gas turbine elements: first stage blades. The influence of the cooling blade performance using a cooling medium with different parameters was estimated. In addition, a comparison of the cooling efficiency of steam and air was implemented. ANSYS software was used for the calculations.

2. Description of the computation model

2.1. Geometry model

Calculations were based on a geometry model of a gas turbine blade located in the gas flow. The blade and the surrounding gas flow were modeled on the application BladeGen ANSYS, and cooling channels within a blade were configured using the DesignModeler application. The prototype of the cooling channels, their locations, and their sizes were taken from the model described in [7]. For a comparison of the cooling efficiency, two cooling mediums were considered: air and water vapor. The above described model is presented in Fig. 1.

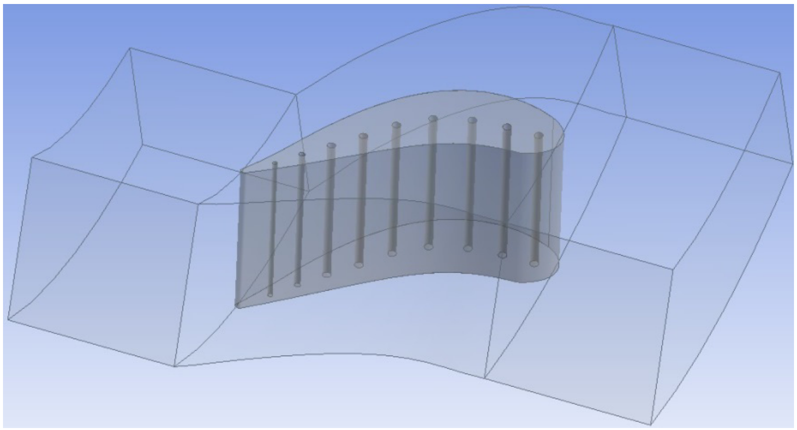

Fig. 1. Geometry model of the gas turbine blade and gas flow.

2.2. Physical properties of the blade material

The blade is made of an austenitic nickel-chromium superalloy Inconel-718. In calculations the following physical properties of the alloy were used: density ρ=8200kg/m^3, specific heat c=435 J/(kg·K), and coefficient of thermal conductivity λ=11.4 W/(m·K) [8].

2.3. Physical properties of air

In the calculations, the air used for cooling the turbine blade was considered with several values of pressure and temperature, with the former varying from 0.1 MPa to 8 MPa and the latter ranging from 373.15 K to 573.15 K. Air is considered to be an ideal gas with a molar mass of 28.966 g/mol [9]. Specific heat was considered as a polynomial function of temperature (1), and this relation is valid in the temperature range from 100 to 1500^{0}C [10]. The coefficients of the polynomial are shown in Table 1.

$$c_p(T) = A_1 + A_2 \cdot T + A_3 \cdot T^2 + ... + A_n \cdot T^{n-1} . \quad (1)$$

Table 1. The coefficients of the polynomial of the specific heat for air.