ADVANCES IN NONLINEAR STRESS ANALYSIS OF A STEAM COOLED GAS TURBINE BLADE

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Abstract—In this paper to study the thermoelastic behavior of a gas turbine blade, a computer code based on Conjugate Heat Transfer method was developed to solve the coupled external flow field and the internal temperature field inside a gas turbine blade. An interpolation method based on the 3D shape functions was used to calculate the correct temperature values at the boundaries to determine the stress field. For the materials with temperature dependent mechanical and physical properties, the thermal stresses exhibit a nonlinear behavior. In these cases, an analytic solution for the energy and equilibrium equations to obtain the temperature distribution and the stress field, knowing \( K(T) \), \( a(T) \), \( E(T) \) would be impossible and the numerical schemes should be employed instead. The results show that the stress for the materials with temperature dependent properties is higher than that for the cases where the blade material properties are constant with temperature. Further, the temperature field and the flow field obtained by the present method were compared to the available experimental findings. The results show a good agreement.

Keywords—Nonlinear stress, Cooling, Temperature dependent, CHT method.

I. INTRODUCTION

In recent years, interest in design and analysis of sensitive elements of gas turbines as a power product is increased. One of the main negative aspects of gas turbine units can be erosion of its hot parts which increases the maintenance cost. The main element of a gas turbine is its blades which from design technology point of view, production and metallurgy are very important (Mallet et al., 1995). Among turbine stages, the first row blades are very sensitive and vulnerable. These blades are prone to erosion due to the thermal and structural stresses and stresses associated with the centrifugal forces (Amr et al., 2006; Tofighi et al., 2008). For an accurate prediction of the rate of erosion and the harms come to the blades, obtaining stress and temperature distribution and determination of critical points is of great importance.

In the past decades, the maximum working temperature for gas turbine due to temperature limits of the blade materials and lack of cool-treating technology has been limited to about 800°C which is the main reason for low efficiency of these turbines. Various attempts have been made so far to improve the working conditions of the blades and reduce the effect of external flow on the blade and enhance the gas turbines efficiency.

With advent of superalloys which in general are Nickel-base superalloys, increase the temperature limits of the blade up to 300°C. These alloys show high strength at high temperatures and have good strength against erosion. However, erosion problem of these blades have not been solved, and for decreasing the erosion one uses single-crystal coating and directionally-solidification coating methods (Amr et al., 2006).

Conventionally cooled gas turbines are using compressor air for cooling purposes, this method in known as Closed Circuit Steam Cooling. There are several advantages by using compressed air from compressor (CCSC) comparing to the air cooling (Krüger et al., 2001). In several references (Bohn et al., 1995, 1997, 2001, 2002, 2003; Bohn and Schnenborn, 1996; Amaral et al., 2010; Atefi et al., 2010a-d; Montenay et al., 2000; Heidmann et al., 2003; York and Leylek, 2003; Lassaux et al., 2004; Verstraete et al., 2007; Jafari et al., 2011; Bayerlein and Sockel, 1991; Han et al., 2000; Verdicchio et al., 2001) two viewpoints are presented for solving CHT on the basis of meeting continuity of temperature and heat flux over the common boundary of fluid and solid: In the first one, all flow part equations inside the body consist of a unit simultaneous equation system, and continuity of temperature and heat flux is considered implicitly. This method which is known as the conjugate method is computationally efficient and requires only one solver. In this method, the connection between fluid and solid surface is ignored if the continuity of nodes exist (Bohn et al., 2003). This viewpoint is used when external and internal temperature field are coupled (Kassab et al., 2003). The second one which is known as a coupled method, heat and flow field is calculated separately. Heat field inside the solid body and the fluid flow are coupled over solid surface by a proper boundary condition. In this viewpoint, field of inside the blade is considered steady state and is analyzed by a finite element method and flow field over the blade by a finite volume method. Coupling is ignored in numerical and analytical problems, for example, in a turbo machine problem, flow solution and heat transfer is solved separately. A separate heat transfer coefficient for determination of blade temperature field is obtained by solving external and internal flows (Kassab et al., 2003). The advantage of this method is using a standard