Propulsion and Power Research 2015;4(4):221–229

HOSTED BY ELSEVIER

http://ppr.buaa.edu.cn/

Propulsion and Power Research

www.sciencedirect.com

ORIGINAL ARTICLE

Investigating the effect of blade sweep and lean in one stage of an industrial gas turbine's transonic compressor

M.A. Neshat[a,*], M. Akhlaghi[a], A. Fathi[b], H. Khaledi[c]

[a]Department of Mechanical Engineering, Iran University of Science and Technology, Narmak, Tehran 16887, Iran
[b]Department of Mechanical Engineering, K.N. Toosi University of Technology, 470 Mirdamad, Tehran 19697, Iran
[c]Department of Mechanical Engineering, Sharif University of Technology, Azadi St., Tehran 11365, Iran

Received 24 July 2014; accepted 17 July 2015
Available online 11 December 2015

KEYWORDS

Blade sweep and lean;
Stacking line;
Modified blades;
Choke mass flow rate;
Efficiency

Abstract In this paper, the simultaneous effects of the sweep and lean of the blades in one stage of a transonic compressor on its performance have been investigated. Then, with the help of numerical solution, fluid flows over these two modified geometries generated from the original sample were analyzed. Considering the applied constraints, the two generated rotor geometries have different geometrical characteristics; so that in rotor No. 1, the blade has a backward sweep and it is less affected by lean, while in the modified rotor No. 2, the blade has a forward sweep and it is more affected by lean. In the first sample, it is observed that the stage efficiency increases by 0.5% for operating design, while the stall margin reduces, and the chocking mass flow rate diminishes by 1.5%. Also regarding the second modified blade, the results indicate that the stall margin increases, the choking flow rate at the nominal rotational speed of the stage increases by 0.18% and the stage efficiency increases by 1%. The comparison of numerical results also shows that, in the first modified rotor, the pressure ratio of the stage diminishes by 0.01%; while in the second sample, the pressure ratio of the stage increases by the same amount. These results were then compared with the experimental results, showing a good agreement.

*Corresponding author. Tel.: +98 9151334497.

E-mail address: m_a_neshat@yahoo.com (M.A. Neshat).

Peer review under responsibility of National Laboratory for Aeronautics and Astronautics, China.

http://dx.doi.org/10.1016/j.jppr.2015.11.002

1. Introduction

The most important goal in the operation of industrial gas turbine compressors is to achieve a higher performance. For this purpose, the blades should be designed and shaped so that they cause minimum flow losses and the boundary conditions are controlled. The second and most difficult challenge in minimizing the flow losses is to minimize the losses near the hub, which are caused by the secondary flow losses. Currently, in the three-dimensional engineering design of blades, blade sweep and dihedral blades are used for the control of secondary flows in order to reduce the corner stall and prevent low-momentum fluids from returning to the row of blades [1]. The mentioned phenomenon can only be predicted by solving the Navier–Stokes equation three-dimensionally. The amounts of flow rate, pressure and efficiency are strongly dependent on the simulation of the boundary layers of blade and casing wall, which may undergo separation. The reduction of flow and separation in the corner regions of blade and casing wall has the greatest influence on the exact solutions of the simulation.

It is important to investigate the behavior of flow in the first stage, because the flow rate of other stages is a function of the output flow rate of the first stage rotor, and because the loss and efficiency of other stages are strongly influenced by the kinematic and thermodynamic characteristics of the first stage.

1.1. *Sweep and lean of rotor blades*

The effects produced by the sweep and lean of transonic rotor have already been analyzed and explained in many research articles; however, a full and comprehensive definition of the effects of these changes on flow behavior and on overall rotor performance has not been presented. Bergner et al. [2] studied a forward-swept blade in a transonic compressor and realized that rotor-tip forward sweep extended the distance between the leakage vortex originating position and the tip shock so as to delay the leakage vortex breakdown thus resulting in a larger stall margin. Breugelmans and Sasaki [3,4] investigated the effects of blade curvature and sweep in a wind tunnel and found out that the forward sweep and the positive lean of blades are effective in delaying the corner stall and weakening the secondary flow. The findings of these researchers indicate that the use of forward-swept blades reduces the interaction between the shock wave and the casing wall boundary layer and is more effective in increasing the efficiency and the stall margin. Oyama et al. [5] associated the increase of efficiency with the reduction of entropy generation and attributed that to the change of blade geometry by means of lean and sweep. Hoeger et al. [6] studied the forward and backward-swept blades and discovered that the chocking flow rate diminishes in the backward-swept blades relative to the forward-swept blades. By analyzing the results of blade sweep and lean related to rotor 37. KwediKha [7] demonstrated that these changes, even if they occur in a small region in the vicinity of blade tip clearance, influence the whole aerodynamic flow. Nevertheless, these geometrical changes produced no significant improvement in the overall performance of the rotor. Also, by examining the lean and sweep of the blades of a transonic fan, Denton [8] confirmed that blade lean has a greater effect on the improvement of performance and reduction of efficiency than blade sweep.

The effect of blade sweep and lean on fan performance has been explained by Denton and Xu [9]. The effect of these geometrical changes has been well understood by analyzing the gradient of the applied pressure. This pressure gradient is very small compared to the pressure gradient between blades, and this is due to the larger bending of flow lines in sections between blades compared to the meridional surface. Because of the low pressure gradient in the vicinity of the casing wall, blade load cannot change rapidly in the wall-normal direction; as a result, pressure distribution is applied in a region further away from the casing wall, without considering the shape of the local profile. Therefore, blade sweep reduces the blade load at the leading edge and increases it at the trailing edge. For similar reasons, blade lean leads to pressure increase on the pressure surface. In the first research conducted by Denton, it was observed that when changes are created in the stacking line of a blade, the blade sections move in a constant pressure field. The important point regarding the shock waves is that the shock wave must impact the casing wall vertically. Thus, the effects of shock sweep near the casing wall and hub are inevitably lost. As the hub's boundary layer influences the flow behavior at the root of blade, the effect of blade tip clearance on rotor performance is also severe. The closest solutions in the investigation indicate that the displacement of the upstream shock over the hub is due to the strong viscosity effects, which produce a severe choking by the boundary layer near the hub. The anticipated viscosity effects are much greater in the cascade than in the compressor rotor; and this is due to the lack of flow contraction effects in the cascade, which produces more dispersion. Nevertheless, in both samples, it is observed that the shock wave has a strong tendency to remain normal to the casing wall, irrespective of blade geometry.

Numerical and empirical analyses by Hah et al. [10–12] in evaluating the performances of a rotor with radially stacked blades without blade sweep and a rotor with forward-swept blades show that the latter rotor enjoys a higher maximum efficiency and the stall margin in it increases considerably. Also, in a rotor with backward-swept blades, the efficiency increases compared to blades with no sweep, but the stall margin diminishes considerably. Different aspects were investigated to find out how blade sweep influences rotor performance; and the three-dimensionality of the shock wave is one of the underlying reasons. As Hah has explained, the shock wave must impact the casing wall vertically (a phenomenon known as the wall effect). This causes the shock wave to move towards the upstream of flow in the backward-swept blades and downstream of flow in the forward-swept blades; and usually the shock wave that moves downstream is more stable. In addition, in the lower sections of the blade, where the casing wall does not have an influence, blade sweep imposes a strong