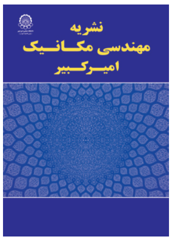

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Computational Analysis of Unsteady Tip Leakage Flow in an Isolated Axial Compressor Rotor Blade Row

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ABSTRACT: Unsteady flow structure, particularly in blade tip clearance region of turbomachines, is one of the main resources of blade vibration, undesirable noise and loss which may eventuate to severe rotating stall and surge. Therefore, analysis of flow behavior in tip clearance region is more significant. In this paper, the unsteadiness caused by blade row tip leakage flow in an axial compressor, is investigated. Analyses are based on flow simulation utilizing computational fluid dynamics technique. For investigation and discussion, two different circumstances at design point and near stall condition are considered. Tip leakage flow frequency spectrum was studied through surveying instantaneous static pressure signals imposed on blades surfaces. Frequency spectrum results showed existence of some pressure peaks at near stall conditions. In this case, interaction between main inflow and tip leakage flow lead to unsteadiness. By occurrence of unsteadiness, tip leakage vortex flow starts to fluctuate at a frequency about the blade passing frequency. However, at design condition, flow is more affected by the main inflow instead of the tip leakage flow.

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1- Introduction

Turbomachines of different kinds have been always used extensively in many engineering applications. Gas turbine engines are amongst the most widely used machines in different industries. The main component of a gas turbine engine can be referred to its compressor, which is frequently known as its heart. As a result, it is of great importance to design and manufacture compressors with high performance. This is more crucial for aero-engines, in which, tendency of designers is to achieve compactness with a wide operation envelope. This will allow to achieve higher thrust to weight ratios, which is one the main objectives of the aero-engine designers. Compact design of compressors means to reduce the number of stages and blades, which in turn, is associated with imposing more aerodynamic loads on each stage. On the other hand, to consider tip clearances for the blades is inescapable. These gaps are naturally associated with flow instabilities which may lead to low performance of the machine from both the thermodynamics and fluid dynamics point of views and also from the structural one. They may cause undesirable noises and may magnify the vibrations of the blades [1]. To optimize aerodynamic design, achievement of higher performance and avoidance of instability, evaluation of relation between tip leakage flow and other flow phenomena is essential. With significant development of numerical methods and computational power, computational fluid dynamics is a proper tool to study complex flows. Different studies about relation between tip leakage flow and stall inception were accomplished [2,3].

While the tip leakage flow has been under prevalent studies for many years, its unsteadiness formation, occurrence mechanism and tip leakage vortex frequency is a new focus in axial compressor research. Thus, in this paper, via unsteady analysis, these subjects are been investigated.

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2- Model Specifications and Numerical Model

Present investigation is carried out for a low speed isolated axial compressor rotor blade row. This rotor also has been used for a number of other experimental and numerical studies [4,5]. This blade row comprises 12 blades with 117.5 mm in its tip chord size and a tip clearance of 2 mm. Test Reynolds number based on the blade mid span chord length and rotational speed of the rotor blade row are 3.77×10^5 and 1300 rpm, respectively.

The well-known commercial flow solver package of Fluent has been used for the current study. The adopted solver is a three-dimensional, viscous, time accurate code that utilizes a finite volume scheme for solution of the governing equations of continuity and momentum. Coupling of velocity and pressure fields was carried out by the usual Simple algorithm. Second order implicit scheme has been applied for time discretization. To estimate the eddy viscosity, the k-ω-SST turbulence model was employed.

3- Results and Discussion

The low speed isolated axial compressor rotor blade row has been chosen as a test model. As mentioned, this compressor has been utilized for numerical and experimental studies about tip leakage flows [4,5]. Fig. 1 shows a good agreement between numerical and experimental results [4].

Results of unsteady analyses of the tip leakage flow of the test model from design point to near stall conditions are

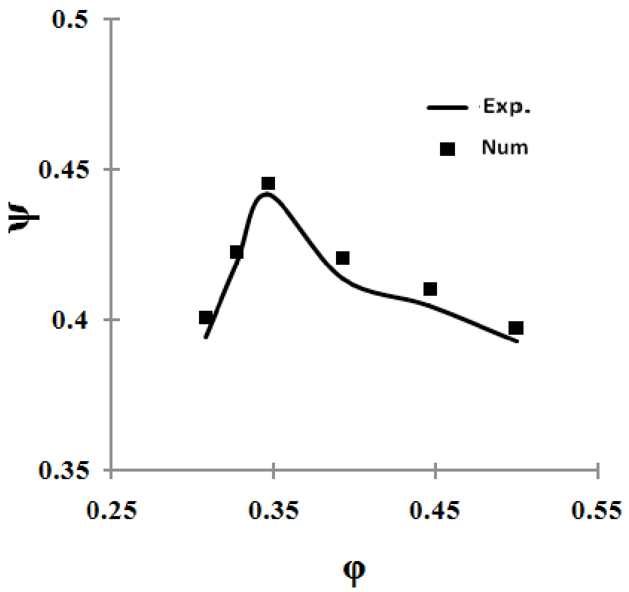

Figure 1. Compressor blade row performance map

presented in this section. These conditions are introduced by different flow coefficients of φ= 0.5 and 0.36. The first flow rate belongs to the design condition and the other refers to condition close to the stall point.

Relative total pressure coefficient (C_{rpt}) results are presented in Fig. 2 at different instances. Streamlines are also superimposed on these figures at T=0. The interface between the main flow and the tip leakage flow can be observed clearly. The region of nearly constant Crpt belongs to the main inflow (the region of red color). In other words, the region prior to this interface belongs to the main stream and after that to the tip leakage flow.

As can be detected from Fig. 2, in design condition (i.e., φ= 0.5), due to the low strength of the tip leakage flow in comparison to the main inflow, a small region of the passage is affected by the tip flow. Consequently, resultant flow at the tip region would be steady. By approaching to the stall flow rate (i.e., φ= 0.36), tip leakage flow gets its dominant effects, and as a result, causes the main inflow to be blocked and turned towards the pressure side of the adjacent blade.

Interactions of the main inflow and the tip leakage flow cause the stagnation point to occur prior to the interface.

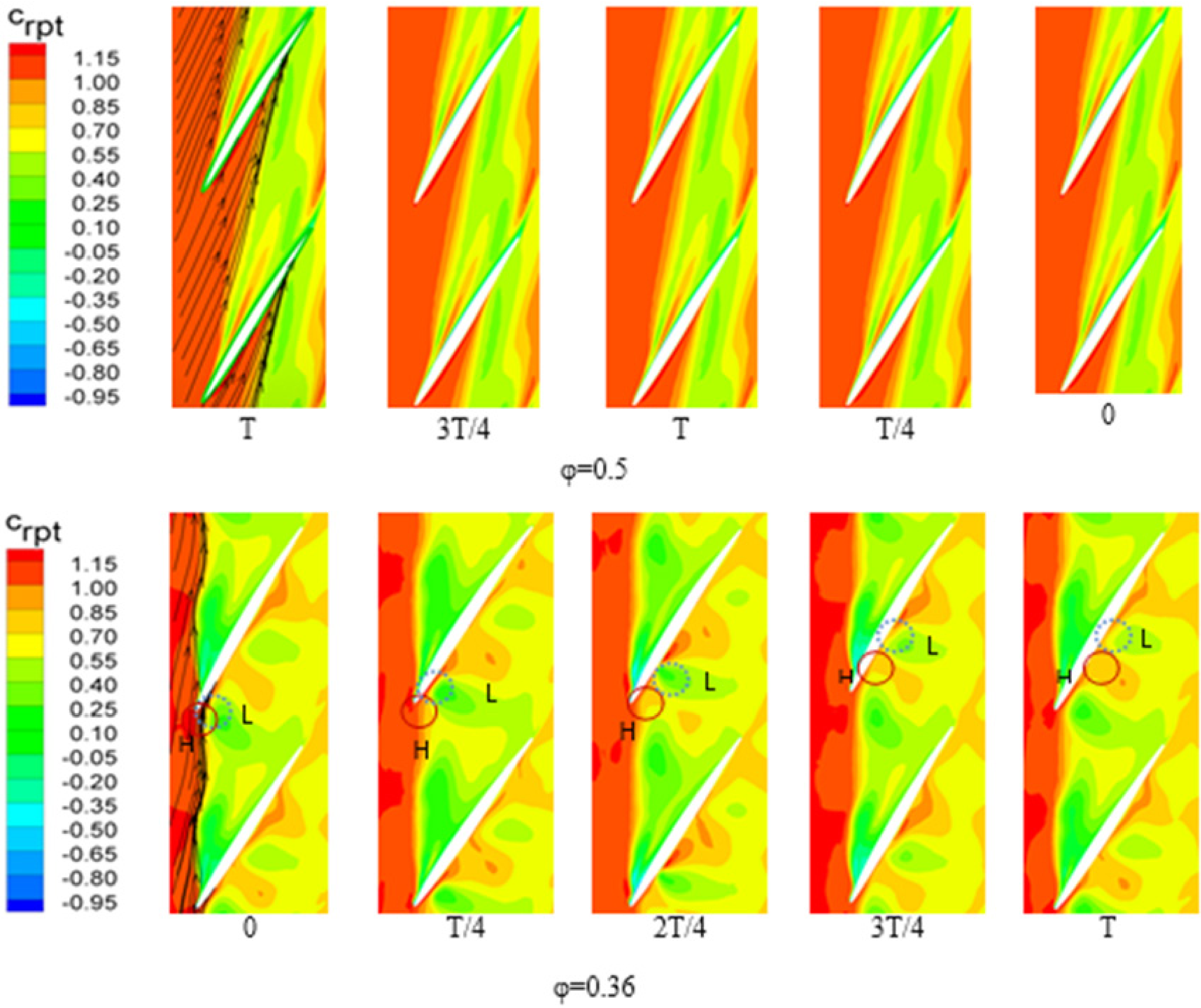

Figure 2. Unsteady fluctuations of static pressures on 97% span stream-surface

This high pressure point pushes the low pressure regions back the interface. Subsequently, due to this pressure difference, flow starts to fluctuate. For a better recognition of this phenomenon, high pressure and low pressure regions are designated by symbols *H* and *L*, respectively, in Fig. 2. Region *H* pushes region *L*, which is the main reason for unsteadiness. Moreover, impingement of the tip leakage flow to the pressure side of the adjacent blade causes further unsteadiness.

4- Conclusions

In this paper, effects of different operating conditions of an isolated axial compressor rotor blade row on unsteadiness caused by tip leakage flow have been studied. Numerical analysis of unsteady tip leakage flow was carried out for different mass flow rates from design point to near of stall conditions. In mass flow rates corresponding to design condition, the flow field of axial compressor is steady. But by reducing the mass flow rate, tip leakage flow is oscillated at frequency about blade passing frequency. In addition, this frequency at all monitored points distributed along blade chord is identical. Unsteady tip clearance vortex. Only can be found at higher loading operating conditions. With the decreasing of the flow coefficient, the unsteady fluctuation of the tip clearance vortex becomes stronger and the frequency becomes lower. The strongest fluctuation always occurs in the region at which tip clearance vortex interacts with the neighboring blade pressure surface.

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