CFD Study on Particle Effect and Erosion in the Axial Compressor Blades and Shroud of Turbomachinery

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Abstract

Fly ash enters axial compressor when a turbomachinery is operated in an adverse environment. We have numerically investigated erosion of the blade and shroud in the turbulent compressor passage flow under the influence of gas-particle two-phase interaction. There have appeared quasi-three dimensional calculations on this subject but not the complete three-dimensional gas-particle interaction as done in the present work. Lagrangian particle tracing technique is used on the base of parallel processing for efficient calculation. Accuracy of the present code is tested using the benchmark JPL nozzle. In the DFVLR compressor blades, we have shown that a large number of particles passing through the tip clearance make impact on the blade tip and on the shroud. Higher degree of erosion is resulted by the heavier particles due to the centrifugal force.
Key Words : *Lagrangian particle tracing, erosion, tip clearance, DFVLR compressor, two-way coupling. three dimension*

1. INTRODUCTION

Aero-engines and gas turbines operating in the polluted environment are often inflicted with intake of pollution particles. Gas turbine efficiency can be deteriorated by the particles passing through the turbomachinery passages. Permanent structural damage may also be incurred in association with the change of component configuration and surface roughness. It is known that surge margin could be lost by erosion due to change in the blade geometry and tip clearance. In order to predict these detrimental effect of particles, a thorough knowledge on the gas-particle interaction and particle impact on the three-dimensional blade surface and shroud is imperative. Computational investigation of gas-particle two-phase three-dimensional turbulent flow is thus important in the turbomachinery industry.

A large number of computer programs have appeared to calculate the transonic turbomachinery flows. Some of them have been well validated and gained much fame as standard design tools in the industry (Dawes[1987], Denton[1995]). In contrast, the two-phase turbomachinery flow has been relatively less investigated despite the important issue of efficiency loss and material erosion. In the literature, particle effect on the turbomachinery was estimated using the empirical equations based on the experimental data of particle reflection and erosion (Tabakoff[1984], Tabakoff[1987], Metwally *et. al.*[1995]). Computational time of these research was relatively very fast since the flow variables were interpolated from the blade-to-blade stream surface result. Accuracy of these computation is, however, limited when there exists significant radial flow, tip clearance flow, or shock-boundary layer interaction in the turbomachinery passage (Katsanis[1965]).

Murthy[1996] has performed an experimental study on the two-phase flow in the single- and multi-stage compressors using a range of droplet size and mass fractions. His results indicated that the single-stage compressor suffered from the heavy aerodynamic loss in the blade tip region. In the multistage compressor, serious reduction of performance was observed. On the other hand, Park & Chang [2000] have performed numerical investigation using the multigrid unstructured adaptive grid on the cascade having intake of solid particles and liquid droplets. They predicted the location and strength of the shock waves, and the surface pressure distribution.

In this paper a numerical method is presented to calculate the three-dimensional DFVLR axial compressor flow subject to particle-gas interaction. We have developed compressible Navier-Stokes code that includes k-ε turbulent modeling and Lagrangian particle-tracking algorithm. The iterative particle-source-in-cell (PSIC) method is used to implement the effect of three dimensional particle motion to the compressor passage flow using the source terms that evolve with numerical iteration.

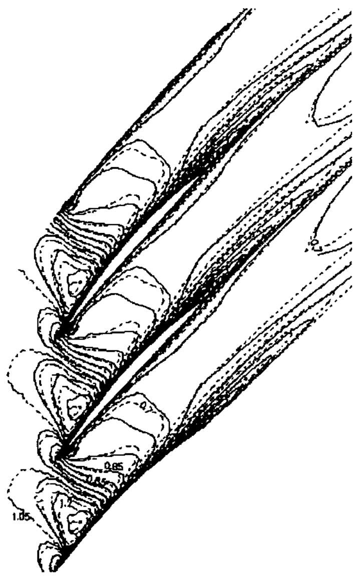

Fig.1 Comparison of contours of relative Mach number at 45% span of DFVLR compressor rotor (—— :gas only, - - -:two-phase(D_p=1.5×10^{-5}, ϕ=0.3))

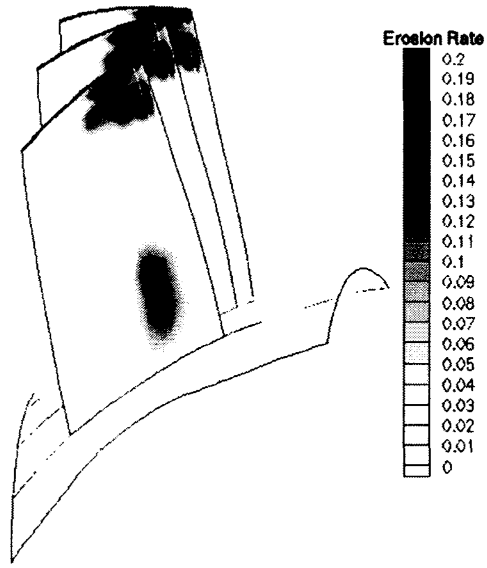

Fig.2 Erosion distribution on the blade surface.