Aerodynamic Optimization Design System for Turbomachinery Based on Parallelized 3D Viscous Numerical Analysis

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Keywords: aerodynamic optimization design, turbomachinery, parallel computation, HPCC

Turbomachinery is important equipment in aircraft engine or power system industries, it has been designed at higher performance now. In order to farther improve its efficiency, we have developed a blade aerodynamic optimization design system for turbomachinery. The present system includes three parts: parametric modeling, optimization strategy and evaluating system.

This paper has constructed a rounded parametric modeling system for turbomachinery blade using NURBS(Non-Uniform Rational B-Spline) technology, which including: 2D NURBS airfoil profile; NURBS stacking line for bending, inclining, sweeping and torsion; 3D NURBS blade surface using NURBS skinning technology; 3D NURBS surface of non-axisymmetric endwall.

The optimization strategies were provided by iSIGHT commercial software. iSIGHT embody the popular optimization method such as GA (Genetic Algorithm), ASA (Adaptive Simulated Annealing), SQP (Sequential Quadratic Programming). We can select anyone of them to do the optimization work, or combine several of them to form a more complex optimization strategy.

Aerodynamic evaluating system is the most important part of the optimization design system, it's also the most time consuming part. It is based on the Computational Fluid Dynamics (CFD) technology. In this paper, we use a kind of higher-order, high resolution and robust 3D viscous flow numerical analysis tool developed by ourself based on full Navior-Stockes equation. During a full global optimization process, we have to perform several hundreds(even thousands) times of aerodynamic evaluation for the different intermediate design points. So the introduction of parallel computation is necessary in order to accelerate the CFD evaluating process up to an acceptable speed.

The most effective way to introduce parallel computation is rebuild the CFD code to parallel mode and using High-Performance Computing Cluster (HPCC). The most natural way to achieve parallelization in CFD is by domain decomposition. This is relatively easy for explicit schemes because the explicit schemes are defined pointwisely and are inherently parallel. In order to achieve parallelization using implicit scheme, we introduce special interface conditions called time-lagging interface conditions with overlapping sub-grid. In previous study, the numerical results show that sometimes the grid overlapping technique will influence the numerical convergence speed and accuracy. But during doing the numerical simulation of steady and unsteady cases for some turbine blade flow using overlapping multi-block grids and time-lagging interfce conditions, we have found it hardly influence the convergence speed and the accuracy of the numerical results with the present LU-SGS-GE implicit scheme and higher-order, high resolution MUSCL TVD scheme. A suitable overlapping width of the sub-grid for domain decomposition is a key point for the present method of parallelization. Here overlapping width is defined in terms of the number of grid points in the overlap.

The hardware platform we used is a HPCC consist of 8 nodes, the configuration of each node

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is: 2X AMD Opteron 246, 2G DDR memory, 2X 1Gbps fast Ethernet interface. We choose an overlapping width of 4 for grid decomposition by considering for the balance of convergence and parallel efficient. Figure 1 shows comparison of the linear speed-up, real speed-up and idea speed-up (theoretic maximum speed-up), the super-linear speed-up is observed from 3 to 10 N_p (number of processors).

We have completed an optimization example of a turbine stator blade[1], using the above aerodynamic optimization design system based on parallel CFD. Figure 2 shows the evaluating history of optimization process. After optimization, the adiabatic aerodynamic efficiency increases 0.95%. Figure 3 shows the comparison of original and optimum 3D shape of blade.

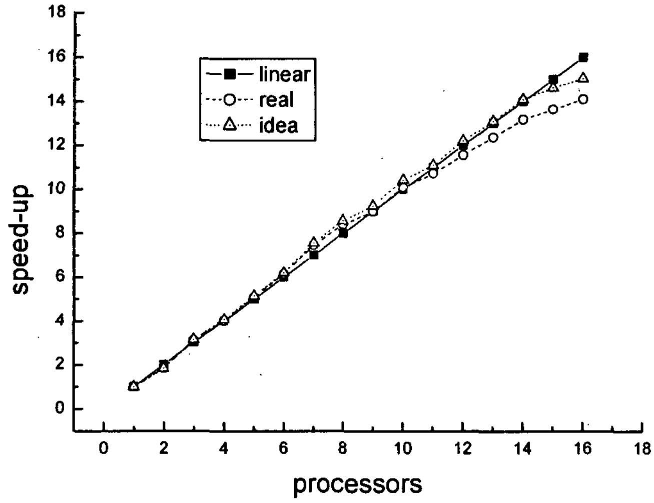


Figure 1. The parallel speed-up coefficient

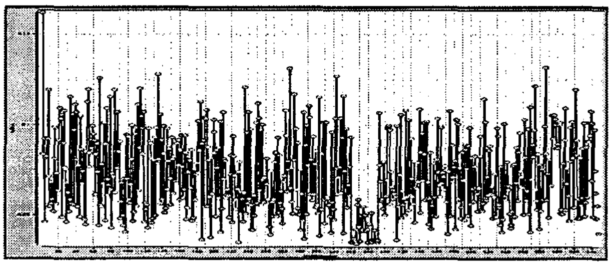
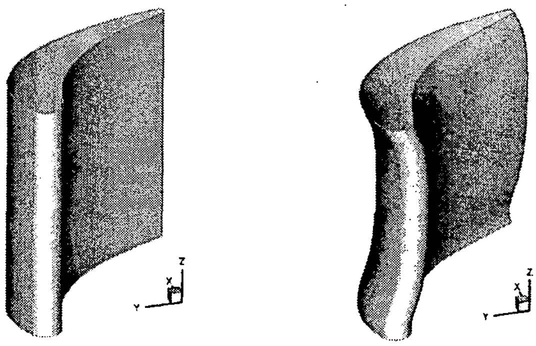


Figure 2. The evaluating history of optimization using ASA strategy



a) Original blade b) Optimal blade

Figure 2. An optimization example of Yamamoto's blade profile

[1] Yamamoto, A., Production and Development of Secondary Flows and Losses within a Three Dimensional Turbine Stator Cascade. 1985, 85-GT-217.