Aerodynamics and Heat Transfer Studies of Parameters Specific to the IGCC-Requirements: Endwall Contouring, Leading Edge Filleting and Blade Tip Ejection under Rotating Turbine Conditions

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Design and Optimization of Endwall Contouring

Introduction

Blades of high pressure turbines have a relatively small aspect ratio that produce major secondary flow regions close to the hub and tip. The secondary flows caused by a system of hub and tip vortices induce drag forces resulting in an increase of secondary flow losses and thus a reduction of stage efficiency. Given the high level of technological maturity and the current state of turbine aerodynamic efficiency, major efficiency improvement, if any, can be achieved only by significant R&D effort.

In contrast, moderate increase in aerodynamic efficiency is attainable by reducing the effect of parasitic vortices such as those mentioned above. Introducing an appropriate non-axisymmetric endwall contouring reduces the secondary flow effect caused by the pressure difference between pressure and suction surfaces. Likewise, attaching leading edge fillets reduces the strength of horse shoe vortices. While an appropriate endwall contouring design requires special care, the design of the leading edge fillet is straight forward.

Continuous Diffusion Method

Texas A&M introduced a completely new physics based method to systematically and efficiently design non-axisymmetric endwall contouring. The method utilizes a continuous prescribed deceleration of the secondary flow velocity from pressure to suction surface by a diffuser type of flow path that is thought of a number of narrow diffusers. The diffuser raises the pressure on the endwall suction side thus reducing the secondary flow velocity, the strength of the secondary vortices, the associated induced drag forces and the total pressure loss due to the latter.

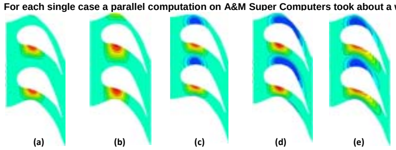
Blade Tip Ejection

Blade tip cooling mass flow ejection is another method for reducing the secondary flow losses at the blade tip. The purpose of this task is threefold: (1) to counteracts the tip clearance vortices and reduces the tip leakage losses, (2) to reduces the flow though the tip clearance, and (3) to obtain optimal cooling without sacrificing too much expensive high pressure compressor mass flow that does not participate in turbine work production. Four pairs of blades with ejection holes were designed. The blades consist of a bottom part and a top part. The bottom parts have the same geometry for all blades with ejection holes, while the top parts having cavities are different due to different ejection hole geometry. From each configuration, two blades will be manufactured and inserted onto the turbine hub.

Conventional Endwall Contouring Design Method

The method used in open literature is a *Trial and Error* Approach:

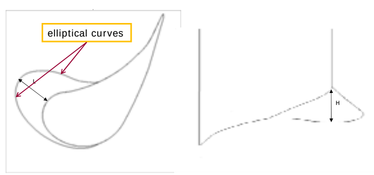
- **Reducing the local area by placing a "hill" on the pressure surface side to increase the velocity, decrease the pressure.**
- **Increasing the local area by placing a "valley" on the suction side to increase the pressure.**
- **Combination of the above.**
- **For turbine rig application, extensive verification and rectification** is essential before producing hardware to be tested.
- **We numerically simulated numerous cases:**
  - **For each individual case several grids were generated to ensure the results were grid insensitive.**
  - **Complete flow field, detailed loss and efficiency analyses were performed.**
  - **For each single case a parallel computation on A&M Super Computers took about a week .**



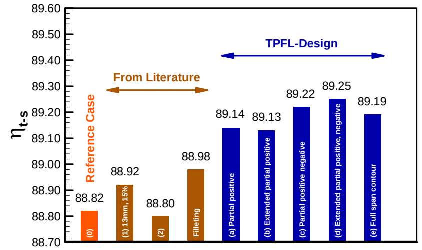
Contour height based on reference case for: (a) partial positive contouring; (b) extended partial positive contouring, full-passage contouring; (c) partial positive, negative contouring; (d) extended partial positive , negative contouring; (e) full passage contouring

Leading-edge Filleting Design

- **The filleting shape is following linear function and the outer shape is limited by elliptical curves.**
- **The filleting extends along the stagnation line.**



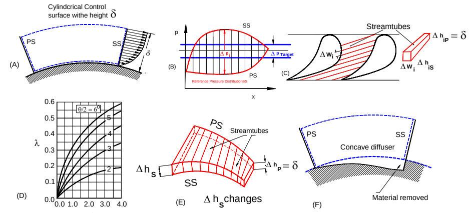
Efficiency Comparison



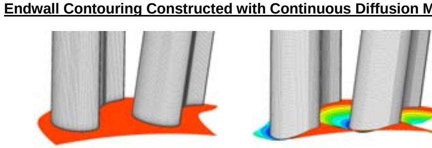
Continuous Diffusion Method for Endwall Contouring

Step-by-Step Instruction:

1) **For the reference blade place cylindrical control surface at a radius R_{hub}+ d with d as the boundary layer thickness developed by the secondary flow from pressure to suction side (Fig. A).**
2) **For the reference blade obtain the pressure distribution close to the hub (about one d) on the suction side (Fig. B) .**
3) **Find the actual pressure difference Δp_i (Fig. B) and define the target pressure difference $\Delta p_{itarget} > \Delta p_{lim}$ (Fig.B).**
4) **Obtain streamlines at the same radial position (Fig. C).**
5) **Based on the diffuser performance map (next slide Fig. D) construct a diffuser (Fig. E) with the constant Δh_{ip} = d at the pressure side and variable Δh_{is} > d on the suction side, follow the pressure recovery diagram to avoid separation.**
6) **Design 3-D contour by removing the hub material (Fig. F).**
7) **Generate a high density grid with for the above design and run CFD with the Menter's SST-turbulence model.**
8) **Re-evaluate results make changes if necessary.**

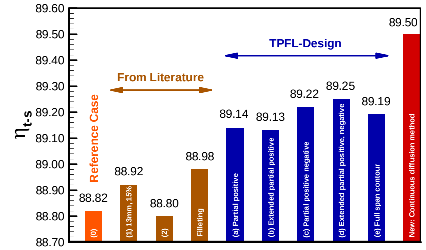


Endwall Contouring Constructed with Continuous Diffusion Method

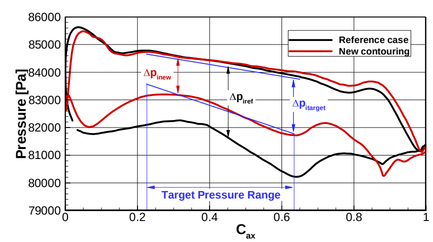


Non-contoured | new contouring method

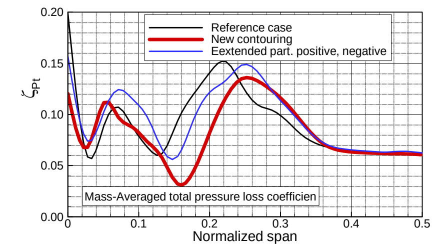
Efficiency Comparison



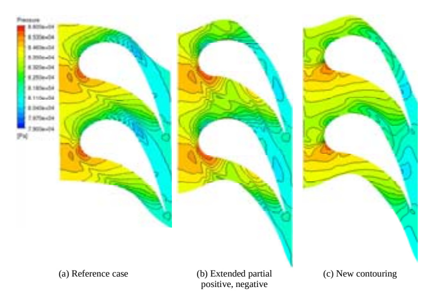
Blade Loadings at the Hub



Total Pressure Loss Coefficients

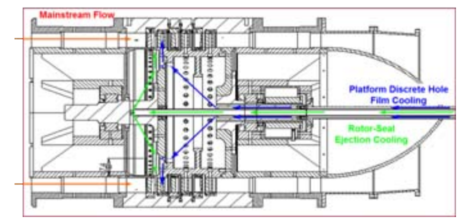


Pressure Distribution at the Hub



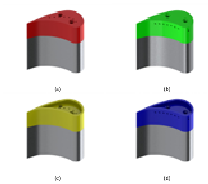
(a) Reference case | (b) Extended partial positive, negative | (c) New contouring

Turbine Rotor Cooling Systems

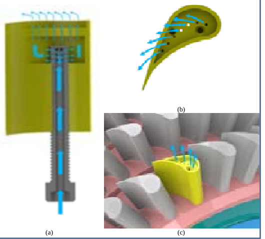


Contouring Ring

Rotor Blades with Ejection Holes



Rotor blades with four different cooling configurations: (a) injection from tip, (b) injection from pressure side near the tip, (c) injection from tip with squealer, (d) injection from pressure side near the tip with squealer. (top)



The coolant flow is injected from the bottom of the bolt and then diffuses into the plenum through radially distributed holes near bolt tip. Finally the coolant flow is ejected through the cooling holes: (a) Cross-section view, (b) Top view, (c) 3D view. (right)