2D UNSTEADY RANS SIMULATIONS OF AN ORGANIC VAPOR PARTIAL ADMISSION TURBINE

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Work principle of partial admission


certain part of the circumference is inactive (covered)
Pros & cons of partial admission

Benefits
- in large steam turbines can be applied in control stages
- in small scale machines:
  - increased aspect ratio (reduced secondary losses)
  - reduced tip clearance loss

Drawbacks
- additional losses (pumping, end-sector, expansion)
- unforeseen excitation frequencies
- unsuitable for reaction stages
- difficult to obtain reliable CFD results
CFD applied to partially admitted stages

Why is it needed?
- Lack of really universal correlative relations for losses
- In order to predict the excitation frequencies

Problems:
- Very time consuming
  - Lack of periodicity
  - Strongly unsteady character at the end-sectors
- Large separations (RANS methods can produce significant errors)
Simplification of the flow

Examples
1. Simulating a stage expanded to full admission
   - periodicity condition
   - losses correlation for partial admission
2. Reducing a 3D domain into 2D in blade-to-blade plane
   - symmetry condition
   - losses correlation for the secondary losses
3. Combining the approach from points 1 & 2

Potential problems with 2D approach
- Flow in partial admission has three-dimensional nature
- Stage must have an appropriate geometry
  - cylindrical hub & shroud surfaces in axial machines
  - hub & shroud surfaces normal to the rotation axis in radial stages
A case study

Assumptions

- Cyclopentane as the working fluid
- Expansion ratio about 20
- Centrifugal flow direction, naturally suitable for 2D CFD analysis
- 1D mean line calculations
- Cyclopentane regarded as a real gas (REFPROP)
Blade design

- The geometry of the blades generated by means of Bezier curves (suitable for optimization)

- Nozzle divergent part designed in a way to provide the expansion to the design pressure (e.g. by method of characteristics to obtain uniform flow)

- Rotor blade designed to fit the flow angles and to obtain constant channel width (one can also adopt the vortex flow method)
The numerical model

- Commercial CFD code Ansys CFX v. 14.0
- Cyclopentane described as a real gas in form of tabularized data (REFPROP)
- Boundary conditions:
  - inlet total pressure and temperature
  - outlet average static pressure
- SST $k-\omega$ turbulence model
- Second order space discretization
- 30 time steps for one rotor blade pass in unsteady simulations
Mesh of the domain

- Computational domain (600,000 nodes)
- Refined rotor mesh (1 mln nodes)
- Refined stator mesh (2 mln nodes)
- Less than 1% change
2D unsteady results (different configurations)
Efficiency vs. admission
Loss estimation

**Superposition principle**

\[
\begin{align*}
P &= P_T - P_P (1 - \varepsilon) - P_S \\
P &= P_T - P_P (1 - \varepsilon) - 2P_S
\end{align*}
\]

for single sector admission

for double sector admission

Where:
- \( P \) – internal power of the partial admission stage
- \( P_T \) – internal power of the stage expanded to full admission
- \( P_P \) – pumping power of the whole rotor circumference
- \( P_S \) – total sector loss for one sector

**Conclusion:**
- Casing on both sides reduced not only the pumping loss (by a factor of about 5) but also the end-sector loss by a factor of more than 3!
- The value of the sector loss is comparable with the pumping loss of the whole rotor circumference (not more than 20% difference)
Combining with 3D steady CFD

Optimal admission for various power outputs

Turbine isentropic efficiency [-]

Admission size [-]

- 30% of \( P_{\text{referential}} \)
- 220% of \( P_{\text{referential}} \)
Conclusions

- Stable 2D blade-to-blade unsteady numerical solutions of flow fields in supersonic turbines working with real gases are possible.

- This approach may be helpful in finding optimal admission sizes.

- The 2D model has obvious limitations and in future should be compared with its 3D equivalent to investigate its reliability.

- Different stage specifications have to be checked such as different blade pitches, different chord sizes and various blade angles.

- The presented design shows a promising performance which in further work will be compared with equivalent centripetal stages.
Thank you!