CHT-analysis of rotor-stator system including radiation

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Agenda

01 Objective and geometry details
02 New methodology for enhanced CHT analysis
03 Description of CHT model
04 CHT analysis results
05 Conclusion and Outlook
Objective:

- Perform conjugate heat transfer analysis of HP turbine assembly. Considering more geometrical details, modeling more physical effects, resulting in more accurate predictions.
- No coupling with external FEA solver due to

Turbine operating point:
\[ \pi_{t-s} = 2.2 \]
\[ n_{red} = 52000 \text{ rpm} \]
\[ p_{outlet\_static} = 2.2 \text{ bar} \]

Inlet boundary conditions:
\[ T_{in\_total} = 750 \^\circ\text{C} \]
\[ \lambda = 1.95 \]
\[ \dot{m} = 3.1 \text{ kg/sec} \]
Methodology options for CHT analysis with MRF

- **CHT of turbine**
  - MRF
    - w/ Mixing Plane
      - Radiation modeling not possible
    - w/o Mixing Plane
      - Circumferential averaging at rotating/stationary interface
        - a) flow fields
        - b) flow fields & heat flux
  - Transient
    - Computation very costly especially with radiation due to varying view factors

Emulating radiation using user heat flux coefficients (source/sink) based on surface temperatures

May result in deviation due to not accounting for view factors and all exposed surfaces

Methodology used for present simulation is shown by red color.
**Fundamental idea:**
Mixing plane interface is an essential requirement in steady-state “Moving Reference Frame” approach to emulate rotating turbine domain. Circumferential averaging of relevant flow field variables is performed at interface of rotating (impeller) & non-rotating (inlet & outlet) domain in order to exchange flow field information between these regions.

In conjugate heat transfer simulation, radiation model is not compatible in combination with mixing plane interface using STAR-CCM+ software, which makes it necessary to find an alternative solution.

**Implemented solution:**
Treating independently rotating and non-rotating domain. No mixing plane interface defined between respective regions. Information communication of decoupled domains by exchanging averaged flow field variables across common interface.

**Loosely coupled fluid model**

- Pressure outlet (average from boundary 2)
- Mass flow rate
- Mass flow rate & flow direction (average from boundary 1)
- Rotating region
- Stationary inlet region
- Pressure outlet
Circumferential averaging methodology details in fluid volume

Fluid-solid loosely coupling: Exchange of circumferential averaged values of HTC, $T_{ref}$ (blue line) & $T_{wall}$ (red line) for heat transfer between solid shroud/heat shield and rotating fluid region.

Fluid-fluid loosely coupling: Exchange of circumferential averaged flow field variables. Enables use of radiation model. (does not work together with mixing plane interface approach)

Leakage flow

Stationary fluid region

Rotating fluid region
CHT model: thermal contact, convection and radiation boundary conditions

- Volute – Outlet Pipe
- Volute – Heat Shield
- Heat Shield – Volute
- Heat Shield – Bearing Housing
- Bearing Housing – Housing Cover
- Disc – Shaft
- Housing Cover – Piston Ring
- Shaft – Piston Ring

Boundary conditions:
- Internal radiation
- Free convection & radiation to ambient
- Adiabatic & radiation off
- Forced convection Oil fog wetted surfaces (gray color)
- Adiabatic
Overview of temperature field

- Relevant fluid flow variables are circumferential averaged at interface of rotating and non-rotating domains in order to emulate the effect of rotating impeller on flow field.

- Heat transfer averaging at solid-fluid interface at shroud/heat shield predicts more realistic circumferentially uniform temperature on shroud and heat shield.
Temperature distribution of solid components

- Circumferential averaging of heat transfer across the shroud solid-fluid interface resulting in banded circumferentially uniform temperature distribution on shroud.
- This will reduce the peak temperatures. Also effects temperature distribution on impeller blades & shroud.
Exhaust flow through the turbine: vector plot & temperature distribution in vertical section

1) w/o radiation, w/o leakage
2) w/ radiation, w/o leakage
3) w/ radiation, w/ leakage

Temperature

low
high

Velocity magnitude

low
high

- contour plot
- vector plot
Study on influence of gas leakage flow to temperature distribution in impeller

<table>
<thead>
<tr>
<th>Leakage Flow</th>
<th>Temperature (°C)</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Volume Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 g/s w/o rad</td>
<td>0 g/s 1 g/s</td>
<td>439</td>
<td>703</td>
<td>647</td>
</tr>
<tr>
<td>0 g/s</td>
<td>0 g/s</td>
<td>440</td>
<td>702</td>
<td>643</td>
</tr>
<tr>
<td>1 g/s</td>
<td>457</td>
<td>699</td>
<td>648</td>
<td></td>
</tr>
</tbody>
</table>

- Significant difference is observed on impeller temperature field due to leakage of 1 g/s as compared to 0 g/s. Temperatures on impeller/heat shield are higher for 1 g/s leakage as compared to 0 g/s leakage. This is due to encapsulation of impeller by hot exhaust gas at back side due to gas leakage flow.
Summary, conclusion and outlook

- CHT requires conduction, convection, radiation as heat transfer modes.
- Software restriction disables radiation in combination with mixing-plane interface.
- Field functions manage data communication between domains.
- Sensitivity study shows: Temperature distribution in solid parts is influenced by radiation and gas leakage.
- All relevant heat transfer modes must be considered to predict reliable temperature distribution in solid parts.

➢ The next step: transient CHT simulation of turbocharging unit…
Thank you for your attention.