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Thermal Management of a Turbocharger for Unsteady Operation

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Company Profile

InDesA

Consulting- & Engineering Services
Simulation and Analysis of complex fluid flow and heat transfer systems for engineering and industrial applications

- Vehicle Thermal Management
- Engine Thermal Management
- Electronics & Battery Thermal Management
- Heat Exchanger Thermal Analysis
- Turbomachinery Flow and Thermal Analysis
and more …

3D CFD/CHT Analysis

1D System Analysis

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Thermal Management of a Turbocharger

Motivation

Complete flow and thermal analysis of a turbocharger:

- Compressor flow
- Turbine flow
- Coolant flow
- Oil flow
- Structure heat fluxes
- Radiation to environment
- Flow driven rotating assembly
Motivation:

Thermal reliability of materials
→ Materials selection, durability, costs

Radiation through turbocharger surface
→ Thermal damaging of adjacent parts; → Heat shields

Oil coking in the slide bearing
→ Oil damaging, bearing damaging; → Cooling concepts

Compression- and Flow loss in the compressor
→ Temperature increase in charging air; → Dimensioning intercooler
→ Influencing local speed of sound and Mach number
→ Influencing acoustic transmission
→ Influencing the compressor filling limits.
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Heat Fluxes on Turbocharger

- **Turbine Housing**
- **Water Jacket**
- **Compressor Housing**
- **Turbine**
- **Compressor**
- **Diffusor**
- **Journal Bearing**
- **Oil Chamber**
- **Labyrinth Seal**

Heat Fluxes:
- $Q_{\text{Air}}$
- $Q_{\text{Exhaust Gas}}$
- $Q_{\text{Cool.}}$
- $Q_{\text{Oil}}$
- $Q_{\text{Convective}}$
- $Q_{\text{Radiation}}$
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Model Description

- **Exhaust Manifold:** Coupled with Compressor Outflow
- **Compressor Outflow:** Time Dependent Pressure Outlet
- **Compressor Inflow:** Stagnation Pressure and Temperature
- **Turbine Inflow:** Pressure Outlet
- **Turbine Outflow:** Pressure Outlet
- **Oil; Coolant:**
  - Inflow: Mass flow and Temperature
  - Outflow: Pressure Outlet

Mesh: $14 \cdot 10^6$ Volume Cells
Polyhedral with 4 Prism Layers

24 Regions
7 Physics Continua
- Air $\rightarrow$ Compressible, Ideal Gas
- Exhaust Gas $\rightarrow$ Compressible, Ideal Gas
- Coolant $\rightarrow$ Temp. dependent property
- Oil $\rightarrow$ Temp. dependent property
- Steel $\rightarrow$ Temp. dependent property
- Alloy $\rightarrow$ Temp. dependent property
- Brass $\rightarrow$ Temp. dependent property
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Mesh details
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Methodology

1D GT-Power Engine Model
Delivers Time Dependent:
- Intake Pressure
- Exhaust Mass Flow
- Exhaust Temperature

3D StarCCM+ turbocharger Model:
Predicts Time Dependent:
- Air Mass Flow
- Turbine Rotating Rate
- Temperature Distribution on Manifold and Turbocharger
- Thermal Stress
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Fluid-Structure Coupling

**Mass Flow in Exhaust Manifold:** Time Dependent

\[ \dot{m}_{\text{Exhaust}} = \dot{m}_{\text{Fuel}} + \dot{m}_{\text{Compressor}} \]

\[ T_{\text{Exhaust}} \approx \frac{\dot{m}_{\text{Fuel}} \cdot H_{\text{Fuel}}}{C_p \cdot \dot{m}_{\text{Exhaust}}} + T_{\text{Compressor}} \]

**Turbocharger Rotating Rate:** Time Dependent

\[ \alpha \approx \frac{M_{\text{Turbine}} - M_{\text{Compressor}} - M_{\text{Friction}}}{J} \]

Where: \( \omega \) = Angular Acceleration

\( J \) = Momentum of Inertia

\[ \omega = f(\alpha; \text{Time}) \Rightarrow \dot{m}_{\text{Compressor}} \]
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Boundary Conditions

Firing Order: 1; 5; 4; 8; 2; 3; 6; 7 (assumed)

From Steady State Solution, the fuel mass flow is assumed to increase linearly:
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Dynamic Result: Acceleration of TC
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Dynamic Result: Acceleration of TC

Heat Shields:
Incident Radiation: = 862 W
Average Temperature = 136 °C

Solid temperature distribution
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Dynamic Result: Acceleration of TC

Gas and Air Temperature @ steady condition:
Rotation Rate = 21500 rpm
Average Exhaust Gas Temp. = 672 °C
Average Exhaust Mass Flow = 0,02315 Kg/s

Gas and Air Temperature after acceleration:
Rotation Rate = 107370 rpm
Average Exhaust Gas Temp. = 549 °C
Average Exhaust Mass Flow = 0,1448 Kg/s
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Dynamic Result: Acceleration of TC
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Dynamic Result: Acceleration of TC

- Exhaust-Outlet mass flow
- Air mass flow
- Fuel mass flow
- Exhaust mass flow
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Dynamic Result: Acceleration of TC
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Dynamic Result: Acceleration of TC

Environment

Turbocharger

Turbine-housing

Wastegate

Turbine

Compressor-housing

Compressor

Coolant: +907 W

Environment

Housing

Bearing

Oil: +91 W

Cooling

Exhaust: -4112 W

Air: +2920 W

Mech. Power
Thank You
For attention

Turbocharger: Thermal analysis