GT Conference 2017: Simulation Tool for Predictive Control Strategies for an ORC-System in Heavy Duty Vehicles

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Content

- Scientific questions and solution methods
- Model intention and model features
- Data acquisition for heavy duty truck
- GT-Model presentation
  - Longitudinal vehicle model incl. ORC-model
  - 1-D engine model
- Predictive control strategies for ORC-system
- Summery and outlook
Scientific questions

• How can a non-stationary heat offering in the commercial vehicle be used to reduce fuel consumption?
• Which potentials offer route and environmental information among with predicted speed and load trajectories to increase the efficiency of a ORC-System?

Methods

• Desktop bound **holistic simulation model** for a heavy duty truck incl. an ORC System
• Prediction of massflows, temperatures and mixture quality (AFR) of exhaust gas
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Model intention / Model features

1D-fluid components and control parameters

- Engine
  - Injection and combustion
  - EGR and TC
- Cooling circuit
  - Pump and thermostat control
  - Coupled Retarder
- ORC-System
  - Working fluid: Ethanol
  - Using of EGR and EAT Heat
  - Electrical regeneration
  - Actuators:
    - ORC Fluid pump
    - Split- and Bypass valves

CAC: Charge Air cooler
EGR: Exhaust gas recirculation
EAT: Exhaust aftertreatment
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Vehicle configuration

- Actros 1845 LS / OM 471
  - 330 kW @ 1800 RPM
  - 2200 (2400 Top Torque) Nm @ 1100 RPM
  - Displacement: 12,81 ltr. / 6 cylinder in-line
  - Maximum Efficiency: $\eta_{\text{eff}} = 46\%$
  - EURO 6
  - Gearbox: 12 gears
- 3 axes tarpaulin trailer
- Overall vehicle mass: 31700 kg
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Measuring scope:
- Temperature, pressure, AFR
- Analysation of video data
- Mass- and volume flow
  - Bosch HFM 7-25.0
  - Volume flow radiator and retarder
  - Venturi nozzle for AGR

J1939 Protocol / OBD II:
- diver load demand
- indicated engine load
- engine speed
- Friction torque
- Injection amount
- Injection begin

CAC: Charge Air cooler
EGR: Exhaust recirculation cooler
FPI: Fuel post injection
EAT: Exhaust aftertreatment
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Autobahn cycle:
Aachen (AC)
Characterized by:
• High density of construction side
• High speed restrictions
• Less road gradient

Autobahn cycle:
Aachen-Frankfurt-Aachen (AC-F-AC)
Characterized by:
• Traffic congestion
• Less speed restrictions
• High road gradient

Aldenhoven Testing Center (ATC) and Rural Road (RR)
• Stationary load points
• Cast down curves
• Breaking tests
Status of the model development

- Vehicle dynamics, transmission and clutch controller
- Forward simulation done by driver model
- Fuel Consumption and heat release done by engine state model
- Operating characteristics of fluid systems: ORC and cooling circuit via Feed-forward controller
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Modelling: 1D GT-POWER engine model / OM 471

GT-POWER Engine Modell OM 471
- Manifold design
- Valve timing
- Combustion
- EGR and Turbocharger performance control

Source: Daimler AG, 2017 www.roadstars.mercedes-benz.com

η_{min} = 0.61
η_{max} = 0.78
n_{min} = 120000 1/min
n_{max} = 300000 1/min
η_{min} = 0.602
η_{max} = 0.692
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Modelling: 1D GT-POWER engine model / OM 471
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Modelling: 1D GT-POWER engine model / OM 471

Measured Temp. before turbine [°C]

Simulated Temp. before turbine [°C]

Measured Temp. after turbine [°C]

Simulated Temp. after turbine [°C]

Increasing $P_{\text{eff}}$
Description of predictive control strategy:

- Multi-physical model vehicle (GT-SUITE)
- Restriction for the system behavior
- Energy prediction for the ORC system
- Basic controller and model predictive control (MPC) of ORC system
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Predictive control strategies for ORC-system

Map based longitudinal vehicle predictor model:

- Designed Environment
  - Legal speed restrictions
  - Speed restrictions by traffic
- Natural Environment
  - Road gradient: $\alpha$
  - Roll resistance: $f_R$
  - Ambient conditions: $T_u$, $p_u$
- Temperatur calculation Map-based with first order delay element $PT1$:

\[
\dot{H}_{in} = \dot{m}_{Ex} \cdot c_p \cdot T_{in}
\]

\[
\dot{Q}_{diss} = \frac{dU}{dt} = \frac{d}{dt} \left( c \cdot m_w \cdot \Delta T \right)
\]

\[
\dot{H}_{out} = \dot{m}_{Ex} \cdot c_p \cdot T_{out}
\]
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Predictive control strategies for ORC-system

Driving profile: Autobahn Cycle AC

- Vehicle speed [km/h]
- Gradient of road [m]

Temperature before turbine [°C]

- Measured
- Simulated

Temperature after EAT [°C]

- Measured
- Simulated

Absolute deviation [%]

Driving Time [s]

Vehicle speed

Gradient of road

Temperature before turbine

Temperature after EAT

Absolute deviation

Vehicle speed [km/h]

Gradient of road [m]
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Summary and outlook

Summary

• A simulation tool for ORC performance analyzation in heavy duty trucks is created
• A strategy for energy prediction to ORC system was presented
• A data base of real driving data has been brought up

Next Steps

• Combining of 1-D engine model with driveline, coolant and ORC sub-systems
• Development of feed-backward controller for ORC system