Investigation of a coolant circuit with controlled water pump and fan

Josua Lidzba, Deutz AG, Cologne
Introduction: the engine TCD 6.1 INDU T4i
Introduction: Outline/Objectives

- Coolant pump (and Fan) statically coupled to engine speed
- About 7.5 % power consumption of pumps and fan at full load (~13.5 kW)

- Replacing static coupling by active controlled components
- Controlling adapted to cooling requirements

- Simulation of effects on fuel/power consumption
- 1D simulation in GTise
Simulation approach: engine model

Engine TCD 6.1 T4i

Thermostat

Radiator

Coolant

Radiator

Coolant

FAN

CAC

Cool air

CAC

Charge air

EAC

Lubricant

EOC

Coolant

EOC

Lubricant

Oil Module

ET

EGRC

Exhaust

EGRC

Coolant

CEO
Simulation approach: heat transfer and simplification

Engine TCD 6.1 T4i

Thermostat

Radiator

CP

FAN

CAC

EOC

EGR

Oil Module

OP
Simulation model: components - waterjacket
Simulation model: components - waterjacket

- Heat distribution
  - 0.2
  - 0.66
  - 0.14

- Thermal masses, 5kg
  - Cylinder lid
  - Head top
  - Liner
Simulation model: components - waterjacket

- Heat transfer coefficient
- Flow velocity dependent at input orifice connection
- Empirical approach, calibrated to a set of measurements

- Influence of heat transfer coefficient and accepted material temperatures
- Main uncertainty

- Coolant mass flow can not be arbitrarily reduced
Simulation model: control system

- Closed loop controlled coolant pump and fan
- Controller input: Coolant temperature and material temperature

- 2 PID controllers
- 2 investigation levels:
  1. Free controlling/actuation of pump and fan speed
  2. Different physical models for controlled devices
     - Visco clutch for coolant pump
     - Fan with adjustable fan blade angle
Simulation model: controll system

Controlled system

\[ z_1 \text{ disturbance (heat flow)} \]

Controlling devices

\[ e_{cp} \]

\[ e_{fan} \]

\[ n_{coolant-pump} \]

\[ n_{fan} \]

\[ T_{coolant}, T_{struct} \]

\[ T_{coolant} \]

PID\_cp

PID\_fan

\[ 95^\circ C/250^\circ C \]

\[ 95^\circ C \]
Simulation model: control strategies

- Controllers behavior engine load depended but not engine speed dependent
- Gains engine load dependent

Proportional and integral gains

- Steady-state vs. transient: faster controllers seem to be possible without oscillations
Simulation model: control strategies

- Quick fan controller, slow pump controller

- Thermostat needed if only coolant pump is controlled

- Acceptable to take maximum material temperatures as target?
Simulation model: calibration, settings, restrictions

- Model calibration:
  - Flow: Coolant mass flow, coolant pressure
  - Engine oil pressure
  - Thermostat opening/closing

- Initial settings (warm engine):
  - 25 °C environment temperature
  - 110 °C oil temperature, 90 °C coolant temperature, 100 °C thermal mass temperature

- 140 steady-state cases
  - Engine speed variation from 800 to 2300 RPM
  - Load (BMEP) variation between ~2.0 and 21.5 bar

- Input data depends on measurements @ 25 °C environment temperature
Results: steady state power consumption

- About 7.5% of effective Power at full load
- Av. coolant temperature: 87.8 °C, Max: 97.6 °C
- Av. material temperature: 193.5 °C, Max: 253.8 °C
Results: steady state power reduction – controlled cool. pump

- Average coolant temperature:
  - 93.5 °C, 5.7 K higher then in uncontrolled simulation
  - Target (95 °C) only reachable at higher loads (material overheating)
- Average material temperature:
  - 222.6 °C, 29.1 K higher then in uncontrolled simulation
  - Target (250 °C) only reachable at lower loads (coolant overheating)
- Power savings between 0.5% and 2.4 % measured in different load profiles
Results: steady state power reduction – *controlled cp and fan*

- Coolant temperature: target (95 °C) reached for every case
- Material temperature: Cooler as with controlled pump only (average 206.1 °C)
- Power savings between 2.0% and 10.9% measured in different load profiles
Results: steady state – *visco clutch and fan w/ adjustable blades*

- Visco clutch:
  - Slip power
  - Inertia (for transient simulations)

- Fan with blade angle control
  - Efficiency?
  - Control range?

- No results yet…
Results: transient power savings

- Wheel loader transient working cycle
- 6000 seconds, high percentage of full load/upper partial load
- Power/fuel savings between 0.5% and 2%
Thank you for your attention!