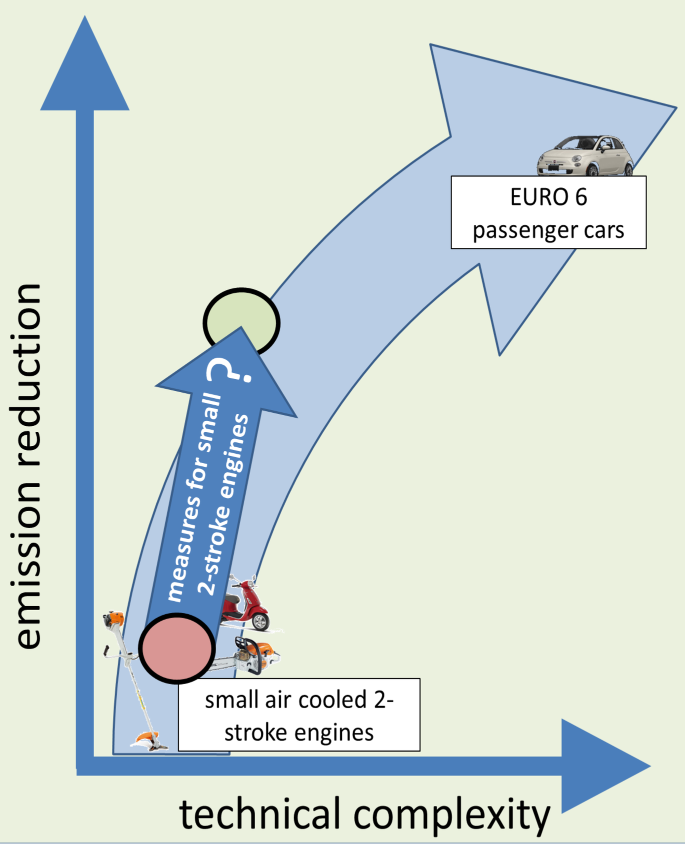
IVT Institut für Verbrennungskraftmaschinen und Thermodynamik · SETC Small Engine Technology Conference · ECO powerdrive · TU Graz

Engine Temperature Model for Air-Cooled 2-Stroke Engines

WHY?

How to reach emission reduction with low technical complexity in the sector of small 2-stroke engines?

In the sector of hand held power tools 2-stroke engines are still the major propulsion technology. With this engine concept it will be very challenging to fulfill the upcoming regulations regarding emissions. In general these engines are very cost sensitive and complex technologies have to be avoided. A promising approach to address these difficulties is the use of an electronic carburetor or a fuel injection system for more accurate fuel metering. In combination with sensors that detect environmental conditions and the engine state an ECU (engine control unit) can perform optimized operations strategies. However, the use of sensors in this engine segment is very difficult. The cost factor and reliability issues are the main reasons for this. A way to avoid a sensor and still be able to predict a physical value is to implement a model of the system that requires available parameters only.



Possible measures to reduce emissions of small air-cooled 2-stroke engines
- **Stratified scavenging** successfully applied
- **Electronic fuel metering** (electronic carburetor, injection) first applications on the market
- **Sophisticated control functions**

Specialized ECU functions
- Sophisticated determination of ignition angle and fuel metering
- Advanced ECU functions
need sensor data e.g. air mass flow, A/F ratio, engine temperature, …

Sensors in 2-stroke engines for hand-held power tools
- Packaging & Weight
  Any additional weight has to be avoided
- Reliability issues
  very high vibration levels may lead to malfunctions
- Costs
  Sensor and additional ECU hardware cause additional costs

→**many types of sensors are very difficult to implement**

Target: Model instead of Temperature Sensor

Engine load → / Engine speed → **Physical Model:**
- Capability of real time calculation
- Calibration based on test bench measurements

→ Engine temperature

HOW?

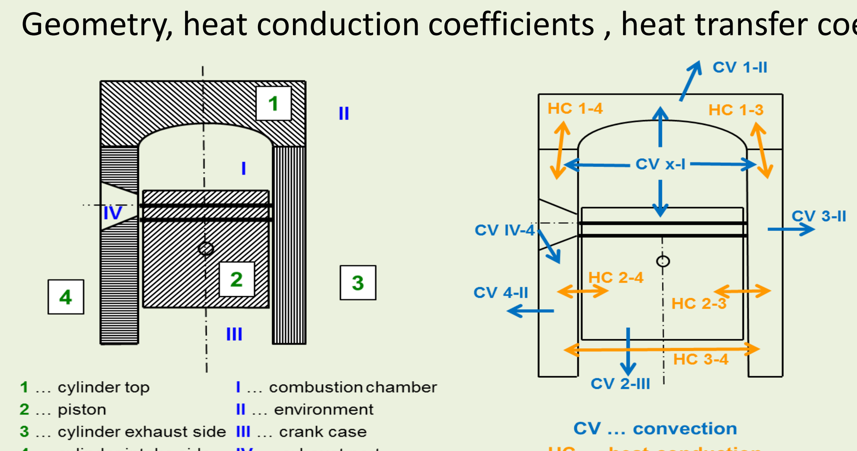
Modelled engine:
- 45cm³
- 2.2kW@9000min⁻¹
- 2-stroke
- Air cooled
- Stratified scavenging
- Hand held application

Modelling approach

Aim
- Create a **simple model** with **real-time capability** (ECU)
- **Calibration** of the model with **test bench measurements**

Approach
- **Partition of the engine in four major thermal cells**
  - Cylinder top
  - Cylinder intake side
  - Cylinder exhaust side
  - Piston
- Heat source → convection combustion gas into cells, friction
- Heat sink → convection cells into environment

Necessary model parameters
- Geometry, heat conduction coefficients , heat transfer coefficients

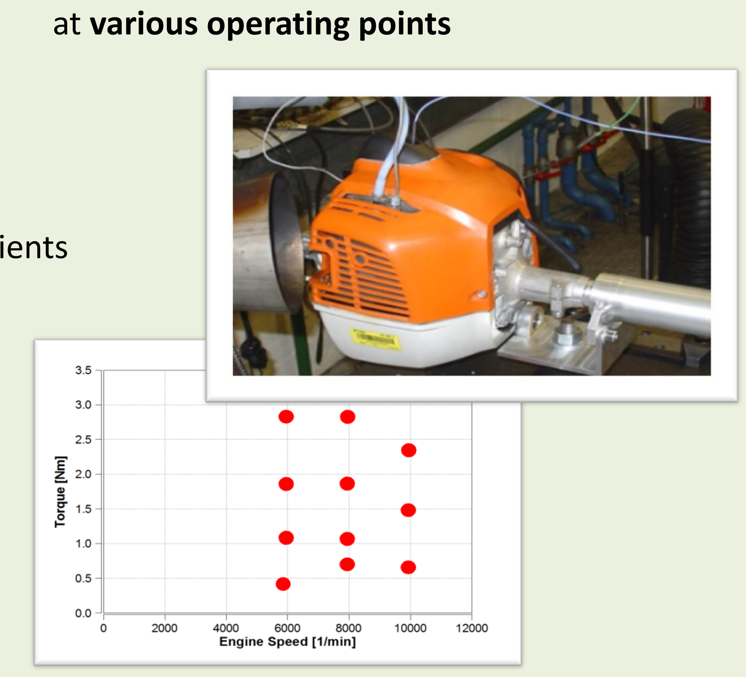


partition in 4 thermal cells and modelled heat flows

Test bench measurements

Measurement of:
- Exhaust gas composition
- Exhaust gas temperature
- Engine temperature (spark plug)
- Mass fuel flow
- Engine speed and torque
- In-cylinder pressure

at **various operating points**

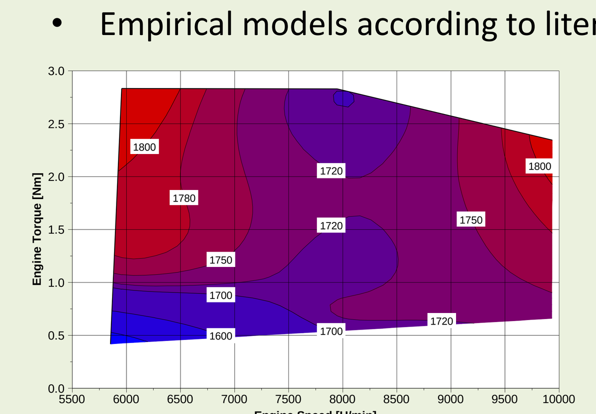


test bench set up and operating points

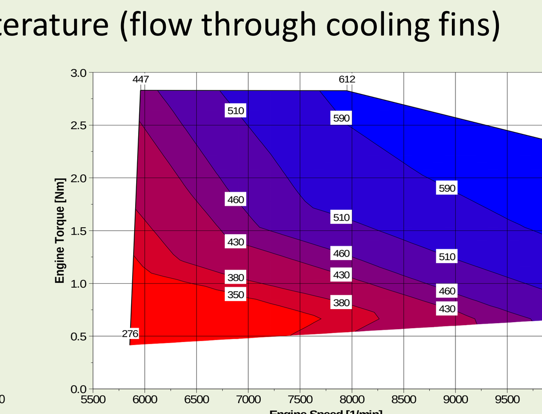
Thermodynamic Analysis

Assumptions and input parameters for **determination** of **the effective in-cylinder heat transfer coefficient** and **gas temperature**
- In-cylinder heat transfer model (Woschni/Huber) 1990
- Mass flow of aspirated air derived from the measured fuel mass flow and the exhaust gas composition
- Trapping efficiency of air and fuel derived from the exhaust gas composition
- Residual gas concentration derived from previous studies (3D-CFD)
- Fuel Specification (C/H/O ratio, caloric value)
- Temperature of cylinder and piston

Assumption for determination of the **heat transfer coefficient between the cells and the environment**
- Empirical models according to literature (flow through cooling fins)



effective in-cylinder temperature [K]

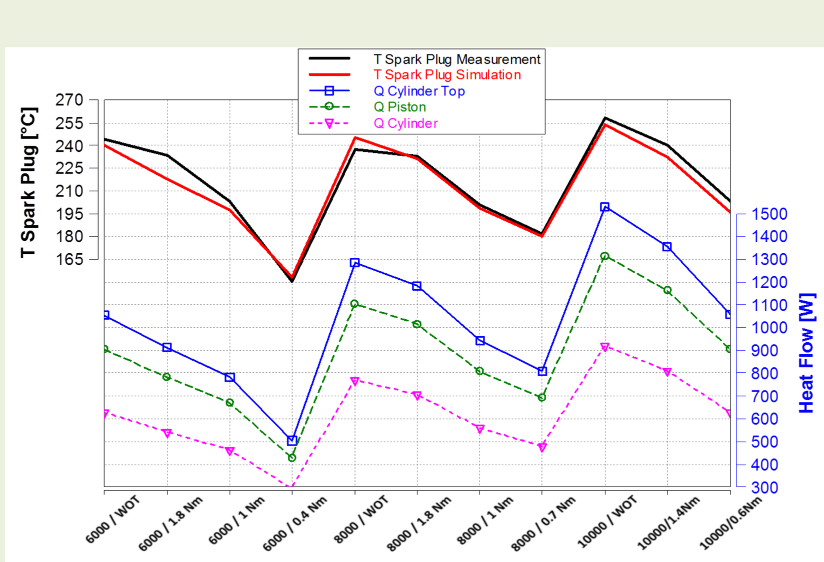


effective in-cylinder heat transfer coefficient [W/m²K]

RESULT

Simulation Stationary Operation

- **Good correlation between test bench measurements and simulation results**
- At some operating points differences of ~20°C



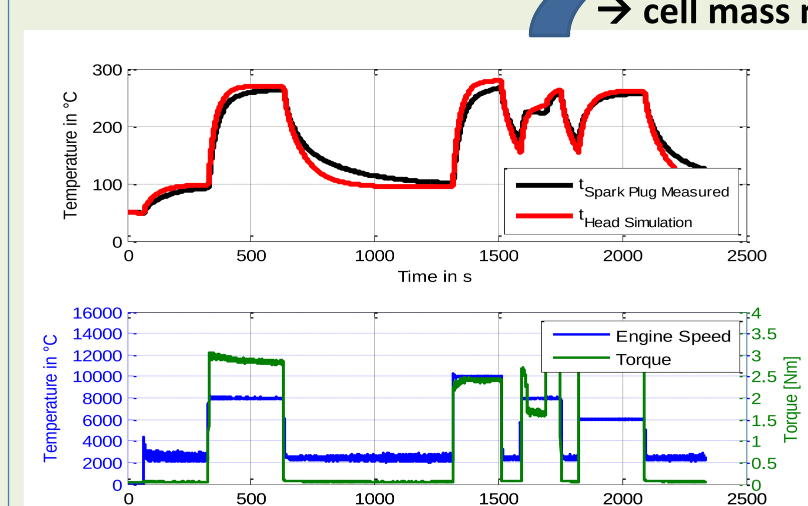
comparison of simulated and measured temperature and the heat flow from the in-cylinder gas to the cells

Simulation Transient Cycle

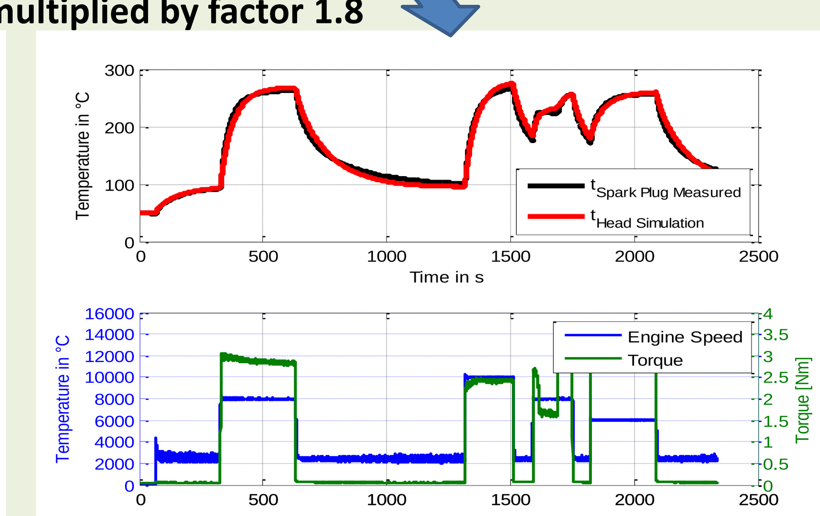
Cell mass according to CAD data:
- Temperature differences
  higher temperature gradient in the simulation
  → due the neglected engine components (crankcase, crankshaft, …)
- Solution strategies
  - additional thermal cells
  - **adjustment of parameters**

Chosen solution to improve transient behavior:
In order to maintain the simplicity of the model, the mass of the thermal cells was scaled by a multiplication factor
→ improved transient behavior
→ low calibration effort

Parameters adjusted
→ cell mass multiplied by factor 1.8



transient behavior with cell masses according to CAD



transient behavior with adjusted cell masses

Summary and Outlook

- Sensors in small air-cooled 2-stroke engines challenging to implement
  → models instead of sensors
- A thermal model for air-cooled 2-stroke engines was implemented and calibrated
  →simple model can be calculated in a ECU
  →calibration of the model by the analysis of a small set of test bench measurements
- Good correlation between test bench measurements and simulation results
- Improvement potentials
  → investigation of a model with more thermal cells and increased complexity
  → consideration of ambient temperature (e.g. chip temperature of ECU)

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