Time-Resolved Flow Measurements for Engine Applications

KTH CCGEX

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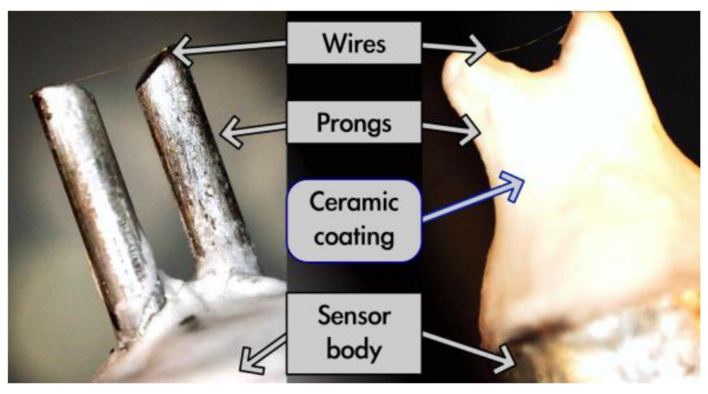
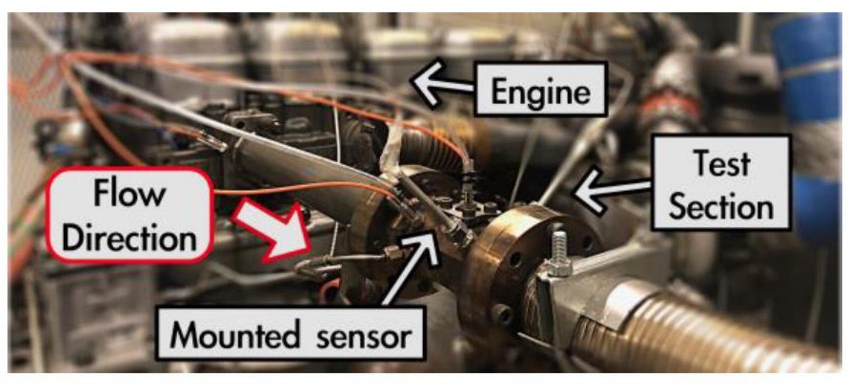
The pulsatile nature of exhaust gas flows in internal combustion engines is often characterized under on-engine conditions by fast pressure sensors while the instantaneous mass flow, velocity and gas temperature are estimated using reduced dimension models. Time-resolved flow measurements of the pulsatile flow under engine conditions remains a pertinent challenge. This study revisits conventional measurement techniques for temperature (resistance wire thermometers and thermocouples) and massflow (pitot tubes) in pursuit of measuring the time resolved exhaust gas temperature/massflow pulse on-engine.

Introduction and Motivation

Time-resolved flow measurements on conventional engine test benches are typically limited to fast pressure transducers. While flow measurement techniques based on laser diagnostics for instance have been applied to ICEs, their adoption is limited owing to a combination of system complexity and the need for an optical access. The relative simplicity in fabricating and integrating resistance wire thermometers, fine-wire thermocouples and pitot tubes to conventional engine test setups motivates further investigation into the application potential of these measurement techniques in the ICE exhaust context. However, a major limitation of invasive techniques lies in the need for compensating the measured signal along with the tradeoff between robustness and response in the case of resistance wire thermometers and fine-wire thermocouples. The study aims to better understand these limitations and evaluates measures to overcome them.

Preliminary Engine Experiments

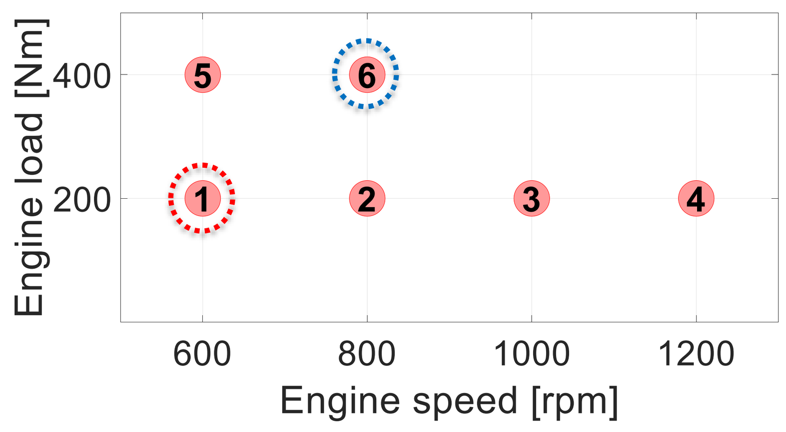




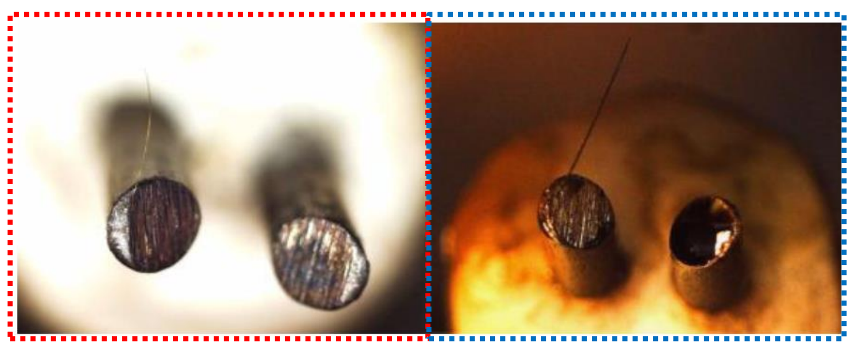
Custom built resistance wire thermometers with Gold coated Tungsten wires (5 and 10 μm diameter) were tested on a purpose built single-pipe exhaust of a Scania D13 6-cylinder HDD engine.

A ceramic coating was applied over the welded joints under the premise that the wire is weakest at the welded joint.

The prototype sensors were tested at conservative engine loads between 2-4 bar BMEP for 15 minutes at each point as shown in the test sequence to the right.

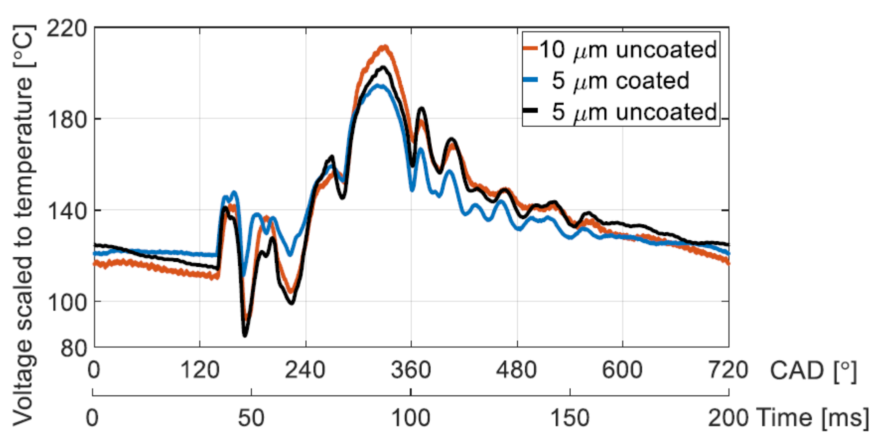


(L) An uncoated 5 μm wire sensor failed after ~7 minutes of operation at P1 and (R) an uncoated 10 μm wire sensor failed after ~85 minutes of cumulative loading at P6.



While uncoated wires failed at the welded joint, the coated 5 μm wire sensor survived operation until P6 i.e. ~85 minutes, thus indicating enhanced sensor life with application of the ceramic coating.

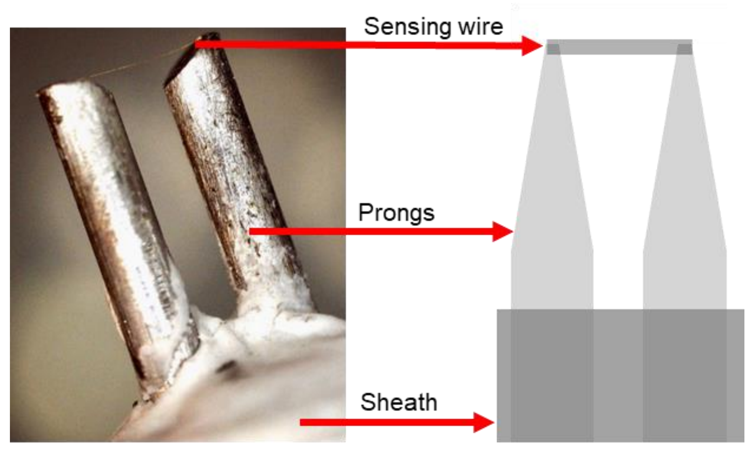
Discrepancies in the sensor response between different wire sizes and the application of a coating prompted the need to understand the implications of sensor design on the sensor system response.



Sensor dynamic characterization will be performed through a combination of shock tube experiments and sensor system response models.

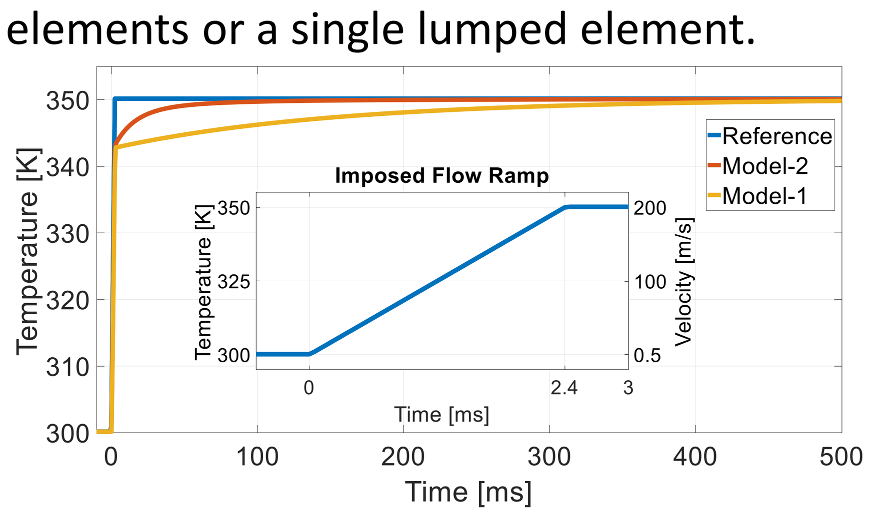
Sensor System Modelling

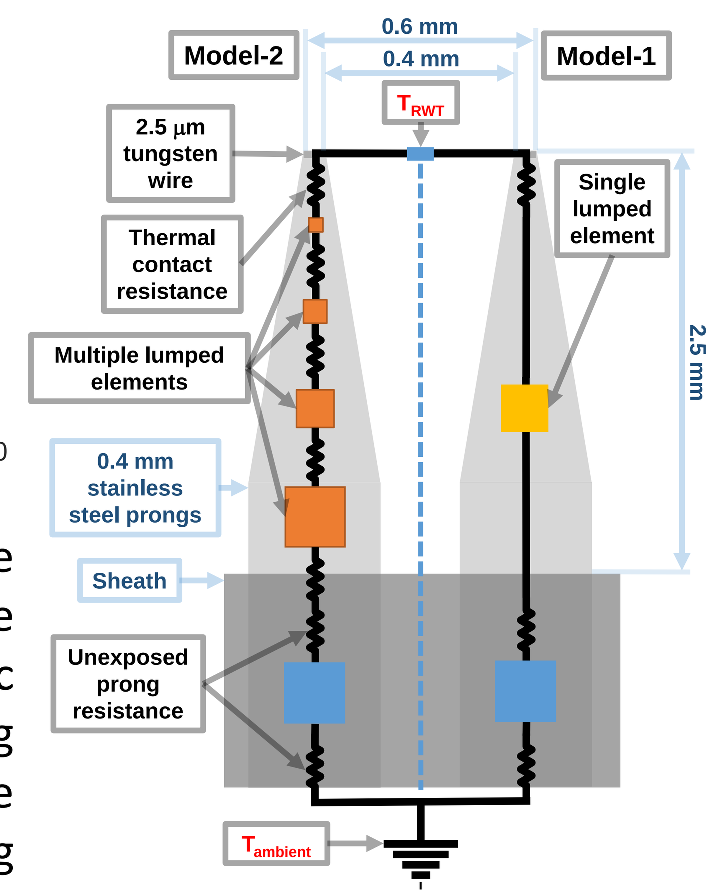
For a resistance wire thermometer, the sensor system includes the sensing wire and the prongs (supports).



A transient heat transfer model derived from literature (lumped parameter approach) of the sensor system was developed in GT-Power.

Disparities were observed in the modelled response of the sensor system depending on the model representation of the prongs as multiple lumped elements or a single lumped element.

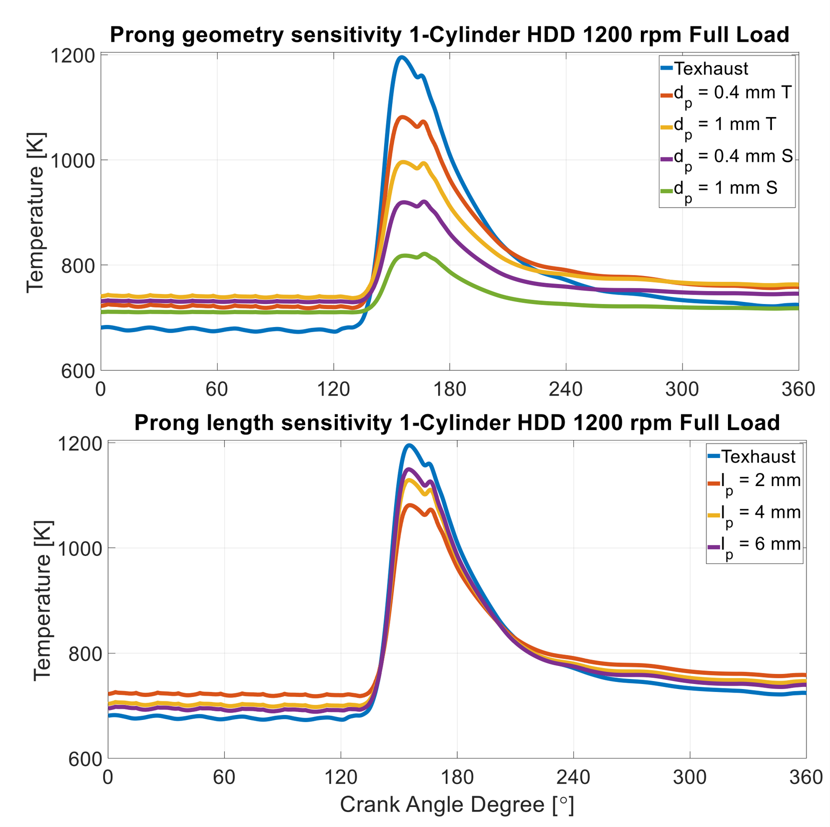




Upon validation with shock tube experiments of resistance wire thermometers with different geometric features such as the wire diameter, prong root diameter, prong length and shape (wedged/cone), the appropriate modelling choice can be determined.

The validated modelling approach can be applied to assess sensor system response sensitivity to different geometric features and engine flows.

(R) An example of prong exposed length, prong diameter and shape sensitivity to a simulated exhaust temperature pulse.



Details shared in SMSI 2020 and SMSI 2021 Venkataraman, V., Murai, Y., Liverts, M., Örlü, R., Fransson, J.H.M., Stenlåås, O. and Cronhjort, A.

Research activities 2021-2023:

- Establish on-engine performance of custom built resistance wire thermometers after high temperature static calibration and dynamic calibration in a shock tube
- Establish applicability potential of pitot tube on-engine for time-resolved massflow/velocity measurement
- Validate the dynamic sensor model with shock tube experimental data and (i) establish sensor modelling considerations (ii) apply the model to understand sensor response sensitivity to geometry and engine flow conditions
- Understand the potential and limits of multiple thermocouple based reconstruction techniques to resolve the exhaust gas temperature pulse

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