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Resistance Wire Thermometers for Temperature Pulse Measurements on Internal Combustion Engines

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Summary:

This study revisits the design of resistance wire thermometers (RWTs) for measuring time-resolved temperature pulsations of the exhaust gas on internal combustion engines. RWTs with gold coated tungsten wires were fabricated and tested on a heavy-duty diesel engine. Experimental results indicate their utility in such harsh environments with the addition of a protective ceramic coating over the welded joints. The influence of the coating on sensor geometry and response will be elucidated through shock tube and gas stand experiments.

Keywords: cold-wire anemometry, exhaust system, pulsating flow, time-resolved measurement

Background, Motivation and Objective

Time-resolved temperature measurements of unsteady flows remain a pertinent challenge. For instance, pulsatile flow measurements on internal combustion engines (ICEs) remain to be addressed. The ICE exhaust constitutes a harsh environment for sensors with maximum temperature (over 1000 °C), pressure (over 4 bar absolute), and flow velocity (over 200 m/s) along with the presence of contaminant particles and vibrations. Incorporating time-resolved temperature data of ICE exhausts in the design process would aid in the further development of turbocharging and aftertreatment systems. This is an enabler towards more efficient and clean ICEs which are expected to remain significant in the effort to curb climate change [1].

Temperature measurement techniques such as radiation thermometry, laser diagnostics and ultrasound have been proven to work under engine combustion conditions [2]. However, their use in standard engine testing remains limited owing to their complexity and the need for optical access. Conventional temperature measurement techniques for engine testing such as thermocouples and resistance wire thermometers (RWTs) show potential for application considering the relatively simple and inexpensive construction. The trade-off between sensor strength and frequency response, however, remains to be addressed. Herein, thermocouples exhibit difficulties in fabrication and unfavourable material properties [3]. While RWTs can be fabricated by welding fine wires in the order of microns, limited studies have been performed under ICE exhaust conditions. Tungsten is a suitable wire material with favourable strength-to-response properties. An anti-oxidative coating is required for high temperature applications, albeit it melts at the weld.

In this study, the design of RWTs is investigated under ICE exhaust conditions with emphasis on the impact of a ceramic coating over the welded joints on sensor life and response.

Sensor Construction

RWTs (or *cold-wires*) are widely used in wind tunnels and turbulence research wherein the flow conditions are significantly different from an ICE's exhaust. Differences include high amplitude temperature pulsations in addition to the aforementioned harsh environment.

Alterations from the conventional design included the use of a high temperature ceramic adhesive and thicker prongs (1 mm steel wire) for reduced deformation and heat loss attenuation. Additionally, the tungsten wires were gold coated. The prongs extended 5 mm from the sensor body to reduce boundary layer interference. The prongs were wedge shaped to maximize the wire aspect ratio and minimize end conduction losses. The wire diameters were 5 and 10 μm. Fig. 1 depicts both uncoated and ceramic coated sensors with a 5 μm wire.

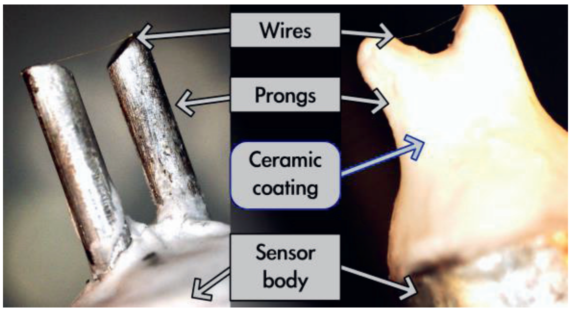

Fig. 1. Uncoated (L) and ceramic coated (R) sensors

Experimental Setup and Methodology

Experiments were performed on a single-pipe exhaust of a Scania D13 heavy-duty diesel engine (see Fig. 2). This setup enables fundamental studies of the exhaust gas flow while protecting the turbocharger from sensor breakdown debris. The test section was equipped with two RWTs, a 3 mm sheathed K-type thermocouple and fast pressure transducers.

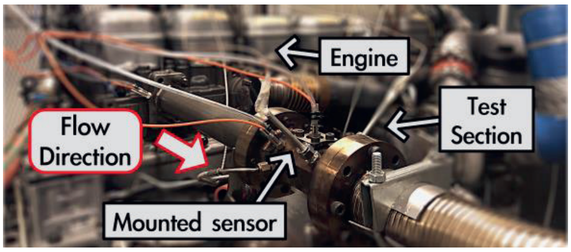

Fig. 2. Single-pipe exhaust with test section

Signal conditioning of the RWTs was performed using Dantec Streamline constant current anemometry (CCA) modules. The signal was sampled at every 0.1 crank angle degrees (CAD). This corresponds to a sampling frequency of 36-72 kHz depending on the engine speed. Fast sampling of 100 engine cycles was performed every 5 minutes until 15 minutes of operation for temperature stabilisation at each operating point. The test sequence is shown in Fig. 3.

Fig. 3. Tested engine operating points

Results and Discussion

The uncoated 5 and 10 μm sensors failed after 7 minutes (at operating point 1) and 85 minutes (at operating point 6) of testing respectively. The wire failed at the welded joint as apparent from Fig. 4. However, the ceramic coated 5 μm sensor endured engine operation until operating point 6. Thus, an over tenfold increase in sensor life was observed with the addition of a ceramic coating. Fig. 5 shows the cycle averaged temperature pulse measured by the sensors after 5 minutes at operating point 1.

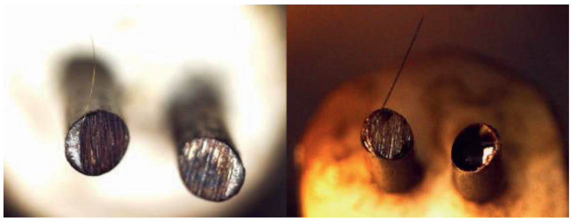
Fig. 4. Wire failure: uncoated 5 μm (L) and 10 μm (R)

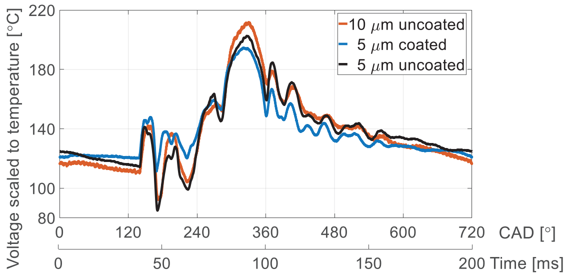

Fig. 5. 100 cycle averaged temperature pulse

Conclusion

Application of a ceramic coating to the welded joints appears to extend sensor life under ICE exhaust conditions. However, its response changed due to the coating. Dynamic response characterisation in a shock tube and sensor design studies in a gas stand will provide insights into the frequency response characteristics of coated sensors. A detailed discussion will be presented at the conference. Testing the developed sensor at higher engine loads will determine the limit of RWTs under ICE exhaust conditions.

Acknowledgements

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