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Measurements and modeling of piston temperature in a research compression ignition engine during transient conditions

E. Mancaruso *, L. Sequino

Istituto Motori - National Research Council, Naples, Italy

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ABSTRACT

The knowledge of piston temperature during internal combustion engine operation represents a precious information to evaluate heat losses and engine efficiency. Experimental measurements of piston temperature during engine functioning is very challenging; hence, modeling this process can be very helpful. In the present work, temperature measurements have been collected using a research compression ignition engine, both in motored and fired mode. They have been used to set-up a 1d model of heat transfer through the piston optical window. A good agreement has been obtained. Moreover, the model can provide information not available from experiments.

Introduction

Heat losses are one of the main issues to be addressed to improve the efficiency of internal combustion engines. At the same time, the thermal status of engine components, as pistons, is needed for an efficient design. In previous works [1,2], the authors measured the temperature of the optical window of the piston engine via thermal imaging and thermocouple installation. The tests concerned steady state and transient conditions. The present work aims to implement experimental data with theoretical results.

Methods

A single cylinder compression ignition optical engine was used. The engine is shown in Fig. 1-A. More specifications can be found in Ref. [2]. The temperature of the external face of the optical window was measured for each engine cycle with a K-type sheathed thermocouple that works up to 450 °C. As shown in Fig. 1eB, the thermocouple was glued using a silicon glue that resists up to 400 °C. This solution was chosen mostly due to the ease of assembly and of accessibility. The two parts, one movable (piston) and one immovable (acquisition system) were set up to get in contact only once per cycle, at the top dead center. The system, set up in the laboratory of Istituto Motori, is reported in the scheme of Fig. 1-C. It consists of the K-type thermocouple, whose hot joint was glued to the sapphire window while the other one was connected to a plate provided with two free pins (Fig. 1-C).

A mono-dimensional model of heat transfer through the window was set up to predict the evolution of the sapphire temperature during the transient. The volume was discretized along the window thickness. The finite differences method was applied to solve the heat transfer problem [3], while the Woschni's correlation [4] was used to calculate the convective heat transfer coefficient. The model was tuned by correcting the in-cylinder temperature and selecting the value that minimized the Normalized Root Mean Square Error (NRMSE).

Results

Fig. 2, left, shows the temperature evolution versus time during engine motored mode at 1500 rpm. The initial temperature is of about 50 °C (cooling water temperature). The measurement finished when the temperature reached a steady value, 220 °C. At this time, the injection was activated: fire mode started. The combustion process produced a new transient temperature (Fig. 2, right). Due to hardware limitations of the optical engine, only 150s of combustion were run. The final temperature, in the graph in fired mode, is not the steady value; it is about 350 °C. The temperature variation is sharper in firing mode, about 1 °C/s, than in motored mode, about 0.6 °C/s.

Experimental data were fundamental to develop and to set-up the model of heat transfer. Modeled and experimental curves of window temperature were reported in Fig. 3, for motored (left) and fired (right) conditions. In motored case an initial delay was observed in the early phase because of the model thermal inertia. The rising part of temperature variation was well predicted and the final value of steady temperature was caught. In fired mode, the main purpose of the model was to evaluate the steady state temperature. In fact, experimental

* Corresponding author.
E-mail addresses: e.mancaruso@im.cnr.it (E. Mancaruso), l.sequino@im.cnr.it (L. Sequino).

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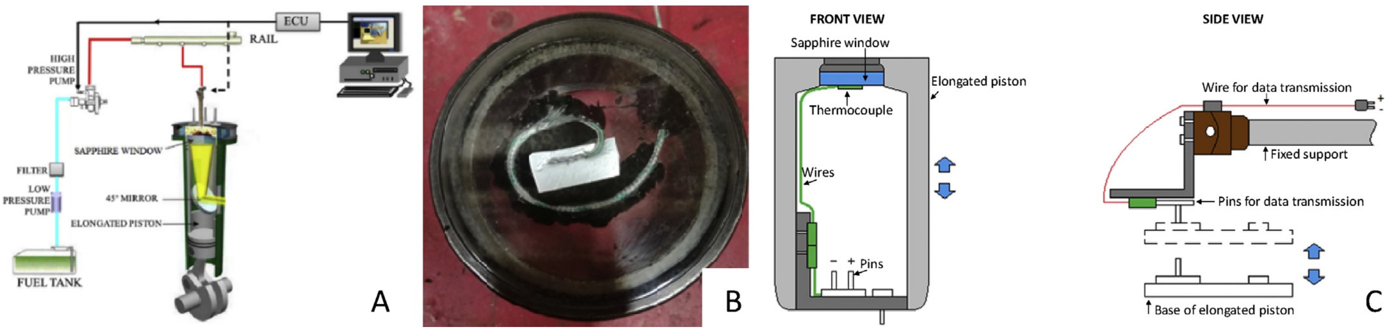

Fig. 1. A) Optical single-cylinder engine. B) Piston window instrumented with a K-type thermocouple. C) the system for the detection of the piston window temperature.

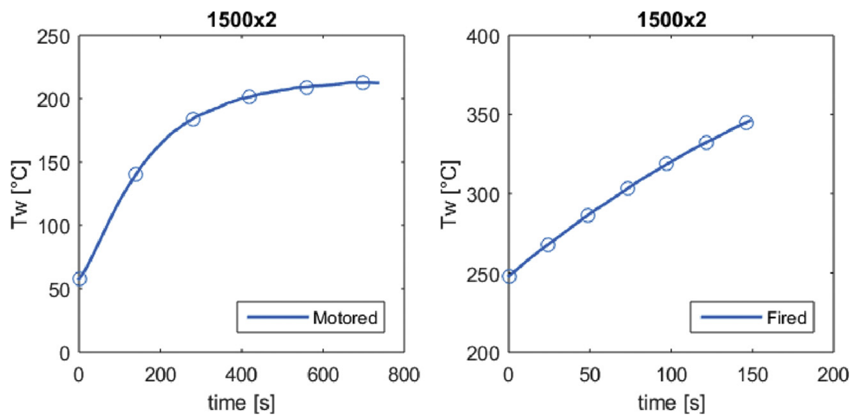

Fig. 2. Transient of temperature in motored (left) and fired (right) conditions at 1500 × 2.

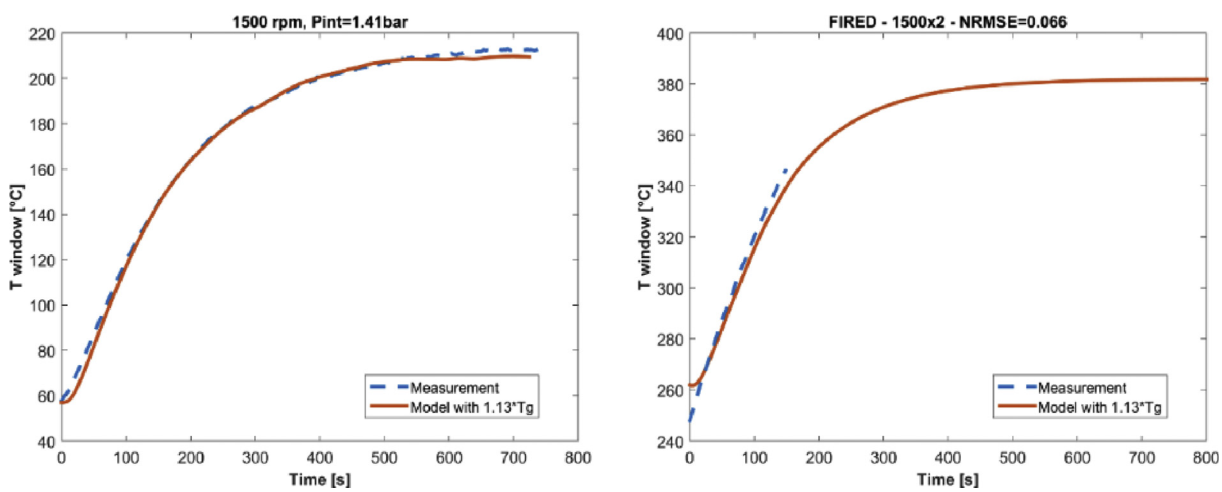

Fig. 3. Simulated and measured transient of temperature on the outer face of piston window at 1500 rpm in motored and fired conditions. NRMSE is 0.015 in motored and 0.066 in fired conditions.

measurements were available only for 150s. Fig. 3, right, in fired mode, shows the model is able to reproduce the curve knee and to provide the final value of the temperature, 382 °C.

Conclusions

An experimental layout to measure the temperature of the moving piston during engine functioning was developed and tested. Experimental data allowed to set-up a model of heat transfer that provided data not available from experiments. Next steps plan to find a more suitable correlation for convective coefficient that does not request to correct the in-cylinder temperature.

Conflict of interest

I declare that there is no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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