Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 101 (2016) 582 – 589

Energy Procedia

71st Conference of the Italian Thermal Machines Engineering Association, ATI2016, 14-16 September 2016, Turin, Italy

A Model Predictive Controller for the Cooling System of Internal Combustion Engines

Teresa Castiglione, Sergio Bova*, Mario Belli

Università della Calabria, Ponte P.Bucci, Cubo 44C, Rende 87036, ITALY

Abstract

The paper presents some results of the Model Predictive Controller (MPC) methodology applied to the case of the cooling system of an Internal Combustion Engine. To this end, a small spark ignition engine, about 1.2 dm^3 displacement volume, is equipped with an electric pump, which is actuated by the controller, independently of engine speed. The goal of the proposed control is to achieve a faster engine warm-up and an effective engine cooling with a much lower coolant flow rate than the one usually adopted, by bringing the cooling system to operate around the onset of nucleate boiling. The developed Model Predictive Control application makes use of a lumped-parameter model, which predicts the heat transfer both in the case of a single-phase forced convection condition and in the presence of nucleate boiling. The performance of the proposed controller is evaluated during the city driving part of the NEDC homologation cycle, which was replicated at the engine test rig. The results show that the proposed controller is robust in terms of disturbance rejection and is effective in reducing warm-up time.

© 2016 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer-review under responsibility of the Scientific Committee of ATI 2016.

Keywords: Internal Combustion Engine, Model Predictive Control, Engine warm-up, Cooling System, Nucleate Boiling.

1. Introduction

The reduction of fuel consumption and the increase of efficiency of Internal Combustion Engines is nowadays one of the most important goals for car manufacturers', owing to the severe requirements of the regulatory agencies on CO2 emissions [1, 2]. The engine thermal management is one of the most promising and low-cost solutions for achieving this goal [3]; the cooling system is therefore widely investigated both by modelling and by experimental

* Corresponding author. Tel.: +39-0984-494828.
E-mail address: sergio.bova@unical.it

1876-6102 © 2016 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer-review under responsibility of the Scientific Committee of ATI 2016.
doi:10.1016/j.egypro.2016.11.074

tests [4-8]. Today, production engines are characterized by poor regulation capability as coolant flow rate is fixed by the engine speed, so that they are over-cooled for about 95% of their operating time [9].

Several strategies were investigated and proposed over the years to regulate coolant flow rates by using electric pumps [9-12]. However, the proposed approaches and control strategies were all based on empirical methods.

This paper presents a more systematic approach to the engine cooling, based on electric pump and low coolant flow rates, which may be working in the presence of nucleate boiling. It is known, in fact, that reducing the coolant flow rate in some operating conditions has the advantages of a faster engine warm-up, lower fuel consumption and CO_2 emission during warm-up and lower pump power under fully warmed conditions. The real question is how much and when the coolant flow rate can be reduced safely. It is commonly accepted that some nucleate boiling is allowed, but severe boiling must be avoided. So, the main goal of this work is the presentation of a methodology for controlling the coolant flow rate.

The proposed methodology is based on Robust Model Predictive Control and on the possibility of predicting the heat transfer regime in the cooling system for given values of engine speed and fuel flow rate. To this aim, a lumped parameter model of the cooling system was developed [13]. The model predicts the occurrence and the extent of the nucleate boiling and calculates the spatial-averaged metal temperature and the average coolant temperature, by the use of simple input data. By taking advantage of the in-line results of the predictive model, a control algorithm, widely described in [14, 15], adjusts the coolant flow rate in order to fulfill the control strategy requirements. Both the engine model and the control algorithm were developed by using the Matlab-Simulink® platform, and were widely validated through test-rig experiments [16].

It is worth pointing out that the proposed methodology has a wide validity and allows the definition of different control strategies for the cooling system according to manufacturers' requirements. In this case, the control strategy aims to gain a fast rise of engine wall temperatures at cold start and, in order to evaluate the advantages of the novel control strategy with respect to the traditional cooling system, the low part of the New European Driving Cycle (NEDC) is imitated in laboratory experiments. The experimental set-up includes an electric pump instead of the standard crank-shaft driven one. Therefore, in order to assess the advantages of the proposed control strategy with respect to the mechanical pump, this last one was 'imitated' by the electric pump by enforcing the coolant flow rates recorded at the roll test bed under the same operating conditions.

2. Cooling system model

For determining the heat transfer mechanism between the engine walls and the coolant, the model makes use of Chen's approach [17], which includes the forced convection and nucleate boiling contributions according to the following equation:

$$\dot{Q}_c = h_{mac} A (T_w - T_c) + h_{mic} A_{nb} (T_w - T_{sat}) \tag{1}$$

In Eq.1, h_{mac} is the forced-convection heat transfer coefficient and is computed through the *Dittus-Boelter* correlation [18], h_{mic} is the nucleate boiling heat transfer coefficient [17], A is the total heat exchange area and A_{nb} is the part of the engine walls involved in the nucleate boiling phenomenon. T_w, T_c and T_{sat} are wall average, coolant average and saturation temperature, respectively. Nucleate boiling occurs only if the total heat flux q_w is higher than the needed one q_{ONB}:

$$q_w \geq q_{ONB} = h_{mac} ((\Delta T_{sat})_{ONB} + \Delta T_{sub}) \tag{2}$$

Therefore, a metrics has been defined [14], NB_Index, which measures the distance of the system thermal state from the Onset of Nucleate Boiling:

$$NB_{Index} = \frac{q_w - q_{ONB}}{q_{ONB}} \tag{3}$$

According to this formulation, the following model was developed [13]:

$$\dot{T}_w C_w = \dot{Q}_g - \dot{Q}_c \tag{4.a}$$

Download English Version:

https://daneshyari.com/en/article/5446502

Download Persian Version:

https://daneshyari.com/article/5446502

Daneshyari.com