Available online at www.sciencedirect.com

ScienceDirect

IFAC PapersOnline CONFERENCE PAPER ARCHIVE

IFAC PapersOnLine 50-1 (2017) 13848–13853

Observer-based fault diagnosis for trucks belt tensioner

Donatien Dubuc *,** **Olivier Sename** **
Delphine Bresch-Pietri ** **Christophe Gauthier** *

* *Volvo Trucks, Saint Priest, France*
(e-mail: donatien.dubuc, christophe.gauthier@volvo.com)
** *Univ. Grenoble Alpes, CNRS, GIPSA-lab, F-38000 Grenoble, France*
(e-mail: olivier.sename, delphine.bresch-pietri@gipsa-lab.fr)

Abstract: This paper deals with the monitoring of a serpentine belt tensioner performance, a critical automotive engine component guaranteeing the cooling system efficiency. A belt tensioner fault will affect the transmission, deteriorate the water pump efficiency, and eventually, lead the engine to stall. Monitoring this component is thus a key to design predictive or corrective maintenance. In this paper, we propose to estimate a parameter which is shown to be characteristic of this component's health by using an Adaptive Observer or an Extended Kalman Filter. Respective merits of these solutions are compared using simulations performed with GT-SUITE on a high-fidelity model.

Keywords: Diagnosis, automotive systems, modeling, nonlinear observers

1. INTRODUCTION

In trucks, multiple peripheral devices such as alternator, water pump or air conditioning compressor are driven by a common belt. This belt, connected to the engine shaft, transmits the necessary mechanical power to all components in line. During the installation, the adjustment of a belt tensioner permits to hold a predetermined amount of tension on the belt, which enables it to fulfill its role.

In case of under-tension, the belt will slip, causing noise and premature wear. More importantly, it will also degrade the operation of all driven components to a subnominal state. Among others, the water pump located in the cooling system will not provide the proper coolant flow rate to the engine. This could lead the engine to overheat and, eventually, stall.

To overcome such problems, this paper proposes to estimate a parameter which is shown to be characteristic of the belt tensioner's health, via an analysis of the cooling system. The first contribution of the paper is to develop a simplified model of the cooling system for diagnosis. As common in the vehicle industry, a model-based approach has been chosen. To estimate the belt tensioner characteristic parameter, two observers have been designed and compared: an Adaptive Observer (AO) and an Extended Kalman Filter (EKF).

Among fault detection strategies (Hwang et al., 2010), the observer-based approach is a popular approach (Chen and Patton, 1999; Ding, 2008) since it introduces analytical redundancy, by estimating unknown parameters or unmeasured state variables from measurements.

The first designed observer is an AO, (Zhang and Clavel, 2001; Besançon et al., 2006) which both estimates an unknown vector parameters and the system states. It has been shown to be effective in several applicative contexts, such as for a permanent magnet synchronous motor in (Tami et al., 2014) or for the degradation of a heat exchanger in (Astorga-Zaragoza et al., 2008). The second one, the EKF, is one of the most used nonlinear observers (see (Chui and Chen, 2009) where theoretical and practical case studies are detailed). Comparison of these two well-known observer-based methods using simulation on a high-fidelity model of the cooling system are then performed. This is the second contribution of this paper.

The paper is organized as follow. In Section 2, a simplified model of the cooling system is presented. In Section 3, based on this model, an Adaptive Observer and an Extended Kalman Filter are designed to monitor the performance of the belt tensioner. Then in Section 4 we analyze the performance of the developed solutions. Finally, conclusions are stated in Section 5.

2. COOLING SYSTEM MODELING

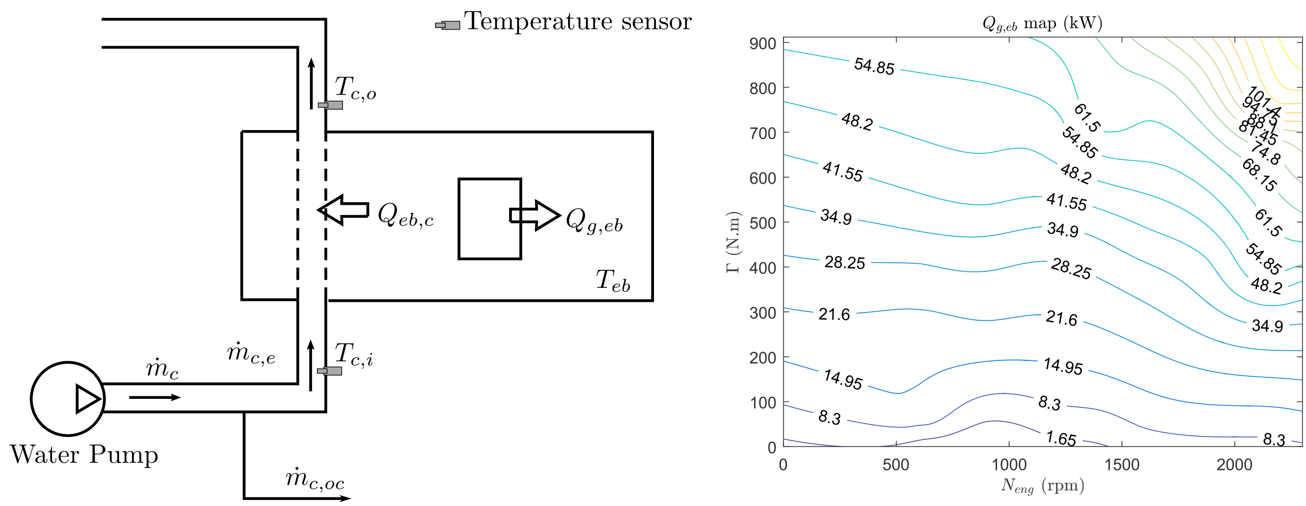
A schematic representation of the heat exchanges involving the engine block is depicted in Fig. 1(a). To protect the different components from overheating and to ensure a good lubrication, the water pump provides the coolant flow rate necessary to remove the heat produced by the combustion.

The next section presents a simplified thermal model that will be used to design observers.

2.1 Thermal modeling of the engine block

To design a control-oriented model, a lumped-parameter approach is followed in the sequel, neglecting the distributed nature of the temperature of the coolant when flowing through the engine block. In details, we follow

10.1016/j.ifacol.2017.08.2226



(a) (b)

Fig. 1. (a) Flows and temperatures of the engine block (b) Heat flow from the gas to the engine block

Table 1. Nomenclature

Notation	Description	Unit
N_{eng}	Engine speed	rpm
N_{pump}	Pump speed	rpm
Γ	Engine torque	N.m
$Q_{g,eb}$	Heat flow from gas in the cylinder to the engine block	W
$Q_{eb,c}$	Heat flow from the engine block to the coolant	W
A_{eb}	Heat transfer surface area inside the engine block	m^2
T_{eb}	Temperature of the engine block	K
$T_{c,\{i,o\}}$	Coolant temperature at the inlet and at the outlet	K
h_c	Coolant heat transfer coefficient	$W.m^{-2}.K^{-1}$
c_{eb}	Heat capacity of the engine block	$J.kg^{-1}.K^{-1}$
c_c	Heat capacity of the coolant	$J.kg^{-1}.K^{-1}$
$\dot{m}_c$	Mass flow rate of the coolant	$kg.s^{-1}$
$\dot{m}_{c,\{e,oc\}}$	Mass flow rate of the coolant through the engine and the oil cooler	$kg.s^{-1}$
$m_{\{eb,c\}}$	Mass of the engine block and of the coolant in contact with the engine block	kg

a procedure similar to (Cortona et al., 2002; Astorga-Zaragoza et al., 2008; Isermann, 2014) where mean-value models are obtained from energy balances.

Let us consider the system presented in Fig. 1(a). It consists in two thermal subsystems: the engine block and the coolant.

Engine block thermal balance. A heat balance on the engine block gives the following temperature evolution:

$$\dot{T}_{eb} = \frac{Q_{g,eb} - Q_{eb,c}}{m_{eb}c_{eb}} \tag{1}$$

Note that the heat flow $Q_{g,eb}$ can be considered as an input of the model. Indeed, this flow depends on the engine operating point and its value can be obtained from a three-dimensional map (cf. Fig. 1(b)):

$$Q_{g,eb} = f(N_{eng}, \Gamma) \tag{2}$$

On the other hand, the heat transfer to the coolant originates mainly from conduction through the area A_{eb}, and thus can be expressed as:

$$Q_{eb,c} = h_c A_{eb}\left(T_{eb} - \frac{T_{c,i} + T_{c,o}}{2}\right), \tag{3}$$

where an average value between the inlet and outlet flow temperatures is used to account for the distributed nature of the flow temperature.

In addition, the heat transfer coefficient h_c can be expressed by phenomenological laws (see for example the Colburn analogy (Bergman and Incropera, 2011)). In our case the following relation is used:

$$h_c A_{eb} = (hA)_{ref}\left(\frac{\dot{m}_{c,e}}{\dot{m}_{ref}}\right)^{0.75} \tag{4}$$

Coolant thermal balance. Following similar arguments, a heat balance equation gives:

$$\dot{T}_{c,o} = \frac{Q_{eb,c} - \Delta Q_c}{m_c c_c} \tag{5}$$

where ΔQ_c represents the heat flow due to the temperature difference at the input and the output of the engine. It can be expressed as:

$$\Delta Q_c = c_c \dot{m}_{c,e}(T_{c,o} - T_{c,i}) \tag{6}$$

Final second-order model. By combining these equations, we finally get the following second order system:

$$\Leftrightarrow \begin{cases} \dot{T}_{eb} = \frac{h_c(\dot{m}_{c,e})A_{eb}}{m_{eb}c_{eb}}\left(\frac{T_{c,o}}{2} - T_{eb}\right) \\ \qquad + \frac{Q_{g,eb}}{m_w c_{eb}} + \frac{h_c(\dot{m}_{c,e})A_{eb}}{m_{eb}c_{eb}}\frac{T_{c,i}}{2} \\ \dot{T}_{c,o} = \left(-\frac{h_c(\dot{m}_{c,e})A_{eb}}{2m_c c_c} - \frac{\dot{m}_{c,e}}{m_c}\right)T_{c,o} \\ \qquad + \frac{h_c(\dot{m}_{c,e})A_{eb}}{m_c c_c}T_{eb} \\ \qquad + \left(\frac{\dot{m}_{c,e}}{m_c} - \frac{h_c(\dot{m}_{c,e})A_{eb}}{2m_c c_c}\right)T_{c,i} \end{cases} \tag{7}$$