Applied Thermal Engineering 87 (2015) 688–697

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research paper

Applying artificial neural networks (ANN) to the estimation of thermal contact conductance in the exhaust valve of internal combustion engine

K. Goudarzi*, A. Moosaei, M. Gharaati

Department of Mechanical Engineering, Yasouj University, Yasouj 75918-74831, Iran

HIGHLIGHTS

- The purpose of this paper is to estimate the thermal contact conductance in exhaust valve.
- The unknown parameters are estimated with inverse heat conduction problem.
- A neural network algorithm proposed to predict the unknown parameters.
- The results showed that the LM algorithm provides the best performance.

ARTICLE INFO

Article history:
Received 28 December 2014
Accepted 12 May 2015
Available online 4 June 2015

Keywords:
Internal combustion engine
Exhaust valve
Contacting heat transfer
Inverse heat transfer
Neural network

ABSTRACT

Exhaust valve temperature increases significantly due exhaust hot gases obtained from combustion fuel-air mixture in combustion chamber of internal combustion engine. In order to avoid the damage of the combustion chamber and the engine itself, heat must be taken away from the valve. This can be done when the valve in contact with the seat and the periodic contact heat transfer takes place. Therefore study of heat transfer contact between the valve and its seat is important and necessary. In this study back propagation neural (BPN) network has been used to estimate two parameters to determine the heat transfer rate through the valve and its seat due the complexity of thermal contact problem between the valve and its seat. This thermal contact problem is solved to obtain the required information for design the neural network using inverse heat transfer method (conjugate gradient method using a two search step sizes). The results show that, between the different algorithms, Levenberg Marquardt algorithm is produced the best model for estimating the unknown parameters.

1. Introduction

Exhaust valve is one of the important components of internal combustion engines that is mentioned as a gorge of engine. Since the exhaust valve temperature extremely increases due the exhaust hot gases of combustion, cooling of valve is essential work. It is clear that the only way to remove heat from exhaust valve when it is in contact with the seat and heat transfer process is periodic contact. So exhaust valve heat transfer problem as one of the most important practical problems of periodic contact heat transfer can play an important role to control temperature of valve and improve engine performance.

In the past, the problem of heat transfer between two periodically contacting bodies has been the subject of a number of theoretical and experimental investigations [1–3]. Investigation of heat transfer in the exhaust valve has always concerned by some researchers. For example, Wisniewski carried out an experimental study to determine the heat transfer coefficients to measure the temperatures and heat fluxes in the exhaust valves of a diesel engine. He conducted a series of experiments to measure temperatures and heat fluxes in the exhaust valve and reported them as a function of engine speed and torque [4]. Hornik et al. studied the determination of temperature distribution, temperature gradient and thermal stresses in exhaust valve. They used different geometrical models of valve that covered by carbon film thickness under different conditions [5]. Paradis et al. proposed a nonlinear dynamic model for the analysis steady and transient heat transfer and periodic thermal contact in valve [6]. Effect of contact pressure

* Corresponding author. Tel./fax: +98 741 2221711.
E-mail address: kgoudarzi@yu.ac.ir (K. Goudarzi).

http://dx.doi.org/10.1016/j.applthermaleng.2015.05.060
1359-4311/

and frequency on contact heat transfer between exhaust valve and its seat was studied by Goudarzi et al. [7]. They indicated that the contact thermal conductivity can be decreased by increasing frequency. Shojaefard et al. studied contact heat transfer coefficient using system identification techniques [8]. Their study focused more on linear models and their results show that between different models ARMAX can be predicted transformation function of with an acceptable error.

Most studies have related to the calculation of heat fluxes and thermal stresses on the exhaust valves and few studies have considered estimating and calculating the temperature valve and heating transfer rate at the contact between the valve and its seat. So far, a suitable model hasn't presented for predicting heat transfer coefficient, calculation heat transfer rate at the periodic contact and finally predicting temperature exhaust valve. Moreover use of electrical and control systems to improve engine performance requires estimation of parameters such as heat transfer rate between the exhaust valve and seat, contact heat transfer coefficient and valve temperature [9]. We need to provide an appropriate model for estimation such parameters to achieve this important goal. Between used methods, use of neural network models is a suitable method to achieve this goal.

In the seventies of the twentieth century, application of artificial networks in internal combustion engine was begun. But in the Nineties its prosperous has been started. Use of neural networks for modeling dynamic systems such as engine has been increased with development in high speed computers. Kangas and Greitzer were designed and performed a network that has the ability of predict heat transfer from cylinder walls and piston of an eight cylinder diesel engine [10]. Thompson et al. trained a network using experimental results that combustion time is input and torque and exhaust gases are outputs of network. These researchers used the network to determine optimal combustion time for operating engine [11]. Heister and Froehlich suggested the use of neural network modeling in calculation pressure inside cylinder at different engine speeds and times [12]. Recently Oğuz et al. predicted diesel engine power with biodiesel using neural networks [13]. The rapid development of artificial neural network technology in recent years has led to an entirely new approach for the solution of inverse heat transfer problems [14–19]. Likewise, the topics of interest to researchers are to present the favorite model for estimation the parameters such as the exhaust valve temperature and the contact heat transfer rate in internal combustion engines.

In this paper, we present an application of Artificial Neural Networks in the estimation of the exhaust valve temperature and the thermal contact conductance in the exhaust valve of internal combustion engine. The inverse heat transfer method is used to determine the input and output parameters of the network, because exhaust valve temperature cannot be measured directly and boundary conditions of problem are unknown.

2. Heat transfer between exhaust valve and its seat

The result of the researches done in the field of contact heat transfer between the valve and its seat show that this process can be considered similar to the heat transfer between two cylindrical rod, as at one of the non-contacting ends is placed hot reservoir (heat source) and the other non-contacting ends is placed cooling reservoir (heat sink) is placed. In this study, two rather long cylindrical rods have been used. To achieve more accurate results and the actual results, the problem of heat transfer in three-dimensional (axial symmetry) is considered. In this study conjugate gradient method is used for estimation heat transfer coefficients. The advantage of the conjugate gradient method is that this method has a high accuracy and fast convergence and the regularization method is used thus tries to deal with the ill-posed problem. In addition no priori information is needed to determine the unknown quantities.

Conjugate gradient method which is based on use of disturbances principles converts inverse problem to solve three easy problems (direct, sensitivity and adjoint problem) with gradient equation. Algorithm of conjugate gradient method is based on this principle to solve the considered contact heat transfer problems [20].

Fig.1a shows the exhaust valve and its seat that specify heat paths. Fig.1b shows the schematic of the geometry of the problem. Two cylindrical specimens similar exhaust valve and its seat are located in contact with frequency f (period τ). $h_c(t)$ is the contact heat transfer coefficient and $h_g(t)$ is the heat transfer coefficient of the exhaust gases. One of the non-contacting ends contact water with temperature T_w and the other non-contacting ends hold at variable heat flux $q(t)$.

Since heat condition has main contribution of heat transfer in this problem thus the governing equation, boundary conditions and initial condition are given by Equations (1)–(12).

Seat region ($0 \le x \le L_S$)

$$k_S\frac{\partial^2 T_S}{\partial x^2}+\frac{k_S}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T_S}{\partial r}\right)=C_S\frac{\partial T_S}{\partial t} \quad \begin{matrix}0\le x\le L_S\\ 0\le r\le R\end{matrix} \quad t>0 \tag{1}$$

$$k_S\frac{\partial T_S}{\partial x}=h_w(T_S-T_w) \quad \begin{matrix}at\ \ x=0\\ 0\le r\le R\end{matrix} \quad t>0 \tag{2}$$

$$k_S\frac{\partial T_S}{\partial x}=h_c(T_V-T_S)+h_g(T_g-T_S) \quad \begin{matrix}at\ \ x=L_S\\ 0\le r\le R\end{matrix} \quad t>0 \tag{3}$$

$$k_S\frac{\partial T_S}{\partial r}=0 \quad \begin{matrix}at\ \ r=0\\ 0\le x\le L_S\end{matrix} \quad t>0 \tag{4}$$

$$k_S\frac{\partial T_S}{\partial r}=h_w(T_w-T_s) \quad \begin{matrix}at\ \ r=R\\ 0\le x\le L_S\end{matrix} \quad t>0 \tag{5}$$

$$T_S(r,x,t=0)=T_i \quad \begin{matrix}0\le x\le L_S\\ 0\le r\le R\end{matrix} \tag{6}$$

Valve region ($L_S \le x \le L_V$)

$$k_V\frac{\partial^2 T_V}{\partial x^2}+\frac{k_V}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T_V}{\partial r}\right)=C_V\frac{\partial T_V}{\partial t} \quad \begin{matrix}L_S\le x\le L_V\\ 0\le r\le R\end{matrix} \quad t>0 \tag{7}$$

$$k_V\frac{\partial T_V}{\partial x}=h_c(T_V-T_S)+h_g(T_V-T_g) \quad \begin{matrix}at\ \ x=L_S\\ 0\le r\le R\end{matrix} \quad t>0 \tag{8}$$

$$k_V\frac{\partial T_V}{\partial x}=q(t) \quad \begin{matrix}at\ \ x=L_V\\ 0\le r\le R\end{matrix} \quad t>0 \tag{9}$$

$$k_V\frac{\partial T_V}{\partial r}=0 \quad \begin{matrix}at\ \ r=0\\ L_S\le x\le L_V\end{matrix} \quad t>0 \tag{10}$$

$$k_V\frac{\partial T_V}{\partial r}=h_g(T_g-T_V)+h_f(T_g-T_V) \quad \begin{matrix}at\ \ r=R\\ L_S\le x\le L_V\end{matrix} \quad t>0 \tag{11}$$

$$T_V(r,x,t=0)=T_i \quad \begin{matrix}L_S\le x\le L_V\\ 0\le r\le R\end{matrix} \tag{12}$$

Assuming constant thermal properties, above equations are the direct problem. Where C_s is the heat capacity per unit volume; k_S, ρ_S and c_S are the thermal conductivity, density and the specific heat of