Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 51(4) (2019) 1-4
DOI:

Improvement of One-Dimensional Simulation of National Engine with Consideration of Heat Transfer and Mechanical Loss Effects in the Turbocharger

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ABSTRACT: Nowadays, Turbochargers play an important role in improving the efficiency, downsizing and pollutant reduction of internal combustion engine. Due to the existence of hot gas flow in the turbine and surrounding air flow in the compressor, the temperature difference between two sides of turbocharger is high and this high temperature difference causes heat transfer from the turbine to the other turbocharger components. The heat transfer reduces the turbocharger performance because some of the hot gas energy has been removed through the heat transfer. There is a need to accurate estimation of the temperature of the turbine exhaust gases to determine the path of the exhaust gases or to determine the boundary conditions of the second turbocharger in engines containing (two-stage turbochargers), and also a need to estimate the compressor outlet temperature as a boundary condition for intercooler and combustion chamber in the absence of an intercooler. In this study, turbocharger one-dimensional heat transfer model is coupled to one-dimensional engine simulation. The results show an improvement (up to 50 °C) in prediction of turbine outlet temperature and also it does not affect other characteristics of the engine simulation such as compressor outlet temperature, turbocharger speed, engine brake power, turbine outlet pressure and etc.

Review History:

Received:
Revised:
Accepted:
Available Online:

Keywords:

Turbocharger
Mechanical loss
Heat transfer
One dimensional simulation

1- Introduction

Nowadays, the internal combustion engine is faced with two problems, including the reduction of fuel consumption and pollutant emissions. To reach this purpose, one of the techniques is turbocharging. One of the most important tools used by automobile engineers for the engine is one-dimensional simulation code, because this simulation is cheap and accurate enough. Inaccurate results of whole the one-dimensional simulation of engine arise from the neglecting of the heat transfer and mechanical loss in the turbocharger. Shaaban and Seume [1] and Shaaban [2] have studied the effect of heat transfer on the compressor performance by using the turbocharger test bench. The study of heat transfer in the turbochargers led to suggestion of different convective coefficients inside turbochargers [3–6].

By using experimental test, Aghaali and Angstrom [7,8], determined the heat transfer in the turbocharger. They considered the heat transfer of the turbocharger with heat sink and heat source for engine simulation and used a Proportional–Integral–Derivative (PID) controller to correct the output temperature of turbine and compressor. Consequently, the use of an efficiency multiplier was reduced for both the turbine and compressor. Serrano et al. [9] investigated the heat transfer of variable turbochargers and the heat transfer model coupled to one-dimensional whole-engine simulation software (GT-POWER).

Some of the power produced by the turbine is dissipated by the mechanical losses. Mechanical loss model is proposed by some authors [10, 11].

In the present paper one-dimensional whole-engine simulation with open wastegate turbocharger was improved for the first time. In this way, the heat transfer and mechanical loss model were coupled to GT-POWER and as a result, the turbine and compressor output temperature were corrected.

2- Methodology

Since the goal is to improve one-dimensional simulation engine, a Lumped capacitance heat transfer model for turbochargers was chosen as described in ref. [12] and presented in Fig. 1. In this model, turbochargers were divided in five metal nodes: the turbine case (T), three nodes for the bearing housing (H_1, H_2 and H_3) and the compressor case (C). Also, there are four working fluids: the hot exhaust gases (Gas), the fresh air (A), the lubrication oil (Oil) and the water cooling (W). Metal nodes were connected to them by means of metal conductance and connected to the working fluids by

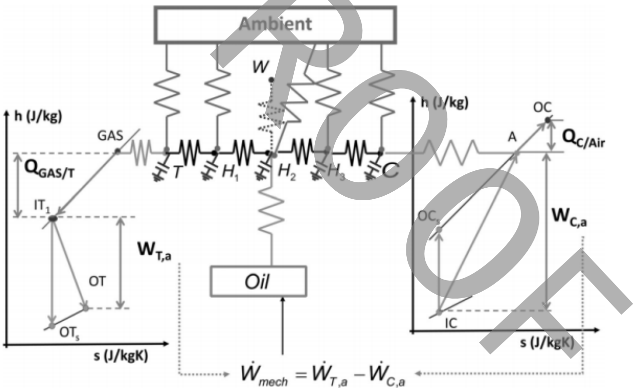

Fig. 1. Lumped capacitance heat transfer model for turbochargers [12]

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means of a convective conductance.

Metal conductance was calculated according to the metal and the geometry of the parts.

Different references have been used to choose the most suitable convective conductance in the model.

According to Eq. (1), Nusselt number of the heat flux from the hot gases to the case-study turbine was proposed [4]:

$$Nu_{Gas/T} = a.\mathrm{Re}^{b}\,\mathrm{Pr}^{1/3}\left(\frac{\mu}{\mu_w}\right)^{0.14}.F$$

$$F = 1 + 0.9756.\left(\frac{D_p/\eta_{\max}}{L_{eff}}\right)^{0.76} \qquad (1)$$

$$L_{eff} = \frac{L_t^{\,2}}{4.D_p}$$

Nusselt number of the heat flux from the fresh air to the case-study compressor was suggested by Eq. (2) [3]:

$$Nu_{air/comp} = \begin{cases} 0.284\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.3} & if\ T_{air} < T_{wall} \\ 0.095\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.4} & if\ T_{air} > T_{wall} \end{cases} \qquad (2)$$

Also Nusselt number of the heat flux from the oil to the bearing housing was determined [3]:

$$Nu_{H2/oil} = 2.51\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.3}\left(\frac{\mu}{\mu_w}\right)^{0.14} \qquad (3)$$

Eq. (4) shows the Nusselt number of the heat flux from the water to the bearing housing [3]:

$$Nu_{H2/W} = 0.096\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.4} \qquad (4)$$

Nusselt number of external forced convection was proposed by the following equation [13]:

$$Nu = 0.3 + \frac{0.62\,\mathrm{Re}^{1/2}\,\mathrm{Pr}^{1/3}}{\left[1+(0.4/\mathrm{Pr})^{2/3}\right]^{1/4}}\left[1+\left(\frac{\mathrm{Re}}{282000}\right)^{5/8}\right]^{4/5} \qquad (5)$$

How to couple the heat transfer model to the whole engine simulation (GT-POWER) is shown in Fig. 2.

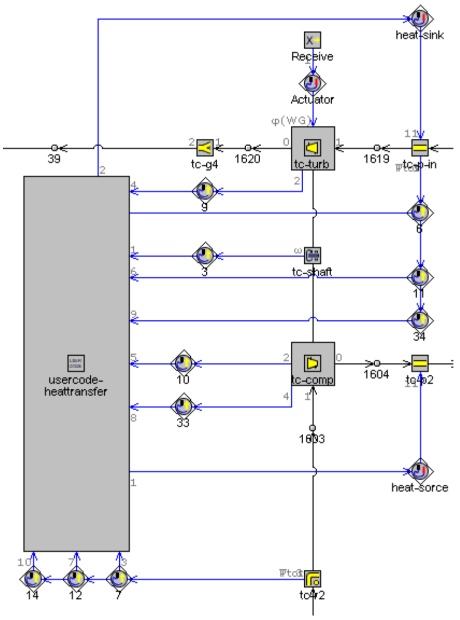

Fig. 2. Heat transfer coupled to GT-POWER

3- Results and Discussion

The result of turbine outlet temperature (Fig. 3) shows that the heat transfer and mechanical loss models coupled to GT-POWER, an improvement (up to 50 °C) in prediction of turbine outlet temperature. The maximum improvement happened in 1500 RPM engine speed, because heat transfer is more effective at slow speeds.

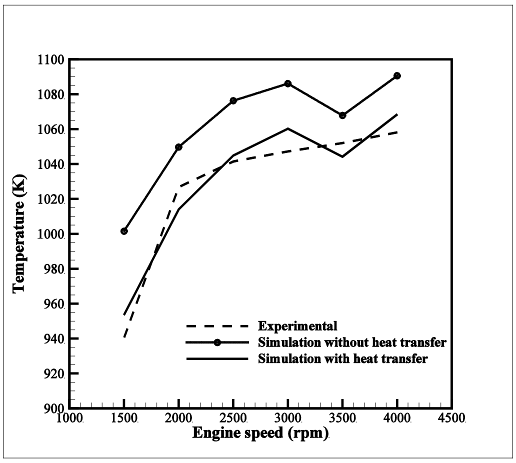

Figure 3. Turbine outlet temperature

Fig. 4 depicts the amounts of heat flows in different parts of turbocharger for each speed of engine. Heat flow from hot gases to case-study turbine is equal to the sum of heat flows of water, oil and fresh air to case-study compressor. In the 1500 RPM engine speed, case-study compressor heat flow is positive, in the other words, case-study compressor temperature is higher than that of the fresh air temperature. In all of engine speeds, Most of the heat flow of hot gases is transferred to the ambient.

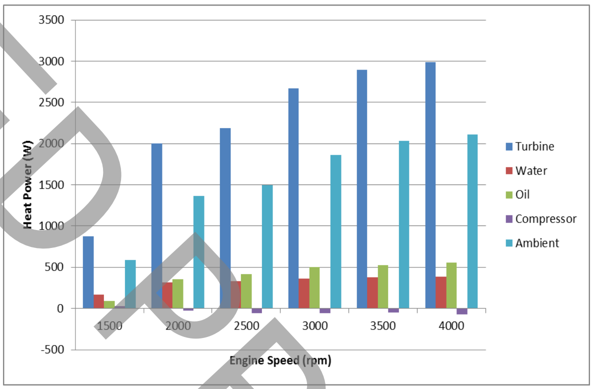

Fig. 4. The amounts of heat flows in different parts of turbocharger

4- Conclusion

In this paper full load tests for open wastegate turbocharger have been simulated by using commercial 1 dimensional software and the results have been compared with the experimental data obtained from an engine test bench. The results are as follows:

- Heat transfer and mechanical loss models are very important for accurate prediction of turbine outlet temperature.
- Heat transfer and mechanical loss models coupled

to GT-POWER do not affect other characteristics of the engine simulation such as compressor outlet temperature, turbocharger speed, engine brake power, turbine outlet pressure and etc.

- The amounts of heat flows in different parts of turbocharger as a function of speed of engine is very important to study the performance of turbocharger.

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M. Kahnooji, S. M. Agha-Mirsalim, S. S. Alaviyoun, Improvement of One-Dimensional Simulation of National Engine with Consideration of Heat Transfer and Mechanical Loss Effects in the Turbocharger, *Amirkabir J. Mech. Eng.*, 51(4) (2019) 1-4.

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