

A Thermodynamic Model for a Single Cylinder Engine with Its Intake/Exhaust Systems Simulating a Turbo-Charged V8 Diesel Engine

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ABSTRACT

In this paper, a thermodynamic model is discussed for a single cylinder diesel engine with its intake and exhaust systems simulating a turbo-charged V8 diesel engine. Following criteria are used in determination of the gas exchange systems of the single cylinder engine (SCE): 1) the level of pressure fluctuations in the intake and exhaust systems should be within the lower and upper bounds of those simulated by the thermodynamic model for the V8 engine and patterns of the pressure waves should be similar; 2) the intake and exhaust flows should be reasonably close to those of the V8 engine; 3) the cylinder pressures during the combustion and gas exchange should be reasonably close to those of the V8 engine under the same conditions for the valve timing, fuel injection, rate of heat release and in-cylinder heat transfer. The thermodynamic model for the SCE is developed using the 1D engine thermodynamic simulation tool AVL BOOST. Besides the pipelines in the conventional intake and exhaust systems, additional pressure wave tuning pipes are added, with which the intake and exhaust systems for the SCE can be tuned to simulate the gas dynamics in the V8 engine. With the tuned intake and exhaust systems, the simulated gas dynamics for the intake and exhaust flows become very similar to those predicted by the thermodynamic model for the V8 engine. Based on the layouts specified in the SCE model, the intake and exhaust systems for the SCE were developed. Good agreements are observed between the simulated and measured intake and exhaust pressures of the SCE.

INTRODUCTION

In the development of a multiple cylinder engine (MCE), the combustion system of the MCE is often first investigated

with a single cylinder engine (SCE). Ideally, the gas dynamics in the intake and exhaust systems of the SCE should simulate those of the MCE in order for the combustion condition in the SCE to represent that in the MCE. In reality, the gas exchange systems for the SCE are often designed only simulating the average pressures in the intake and exhaust systems of the MCE. As a result, the combustion conditions in the SCE are often different from those in the MCE. For the turbocharged diesel engines, amplitudes for the pressure waves in the exhaust system are often on the same orders of the average exhaust pressures, resulting in highly pulsatile exhaust flows. The pulsations in the exhaust pressures have a considerable influence on the gas exchange for the turbocharged diesel engines. The combustion condition in the engine cylinders is affected significantly by the dynamic gas pressures in the intake and exhaust systems. In order to have similar dynamics for the gas exchange, the intake and exhaust systems for the SCE should be designed with the gas dynamics similar to that of the MCE. To do so, the intake and exhaust systems of the SCE may need additional pipe branches to generate pressure waves of various patterns through semi or full blocking of the flow channels, interference and tuning of the pressure waves; the generated and tuned pressure waves can simulate those from the adjacent cylinders and interfere the gas exchange of the cylinder that the SCE targets at. Through tuning the interferences of the multiple pressure waves in the intake and exhaust systems, the gas dynamics for the SCE may be tuned to become similar to that of the MCE [1]. The principles for designing and tuning the gas exchange systems for the piston internal combustion engines have been summarized by Smith and Morrison [1], Winterbone and Pearson [2], and Benson [3]. A good literature review for the previous investigations on pressure pulse generations, wave interferences and tunings are provided in the references [2,3]. In their classical work on

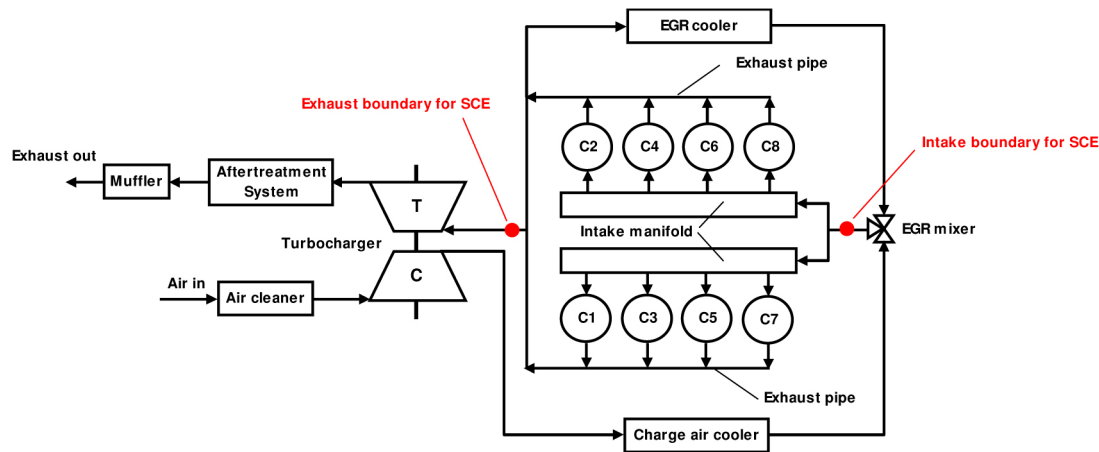


Figure 1. Schematic layout of the turbocharged V8 engine and boundaries for the SCE.

the gas exchange systems, Smith and Morrison [1] also discussed the techniques for tuning the pressure waves in the engine intake or exhaust system using the interferences of pressure waves generated by different pipe branches. The methods for generating pressure waves with various patterns using different pipe branches are discussed in details in the work of Benson [3]. Employing the principles and techniques given in the references aforementioned, it is possible to design the gas exchange dynamics of the SCE simulating those of the corresponding turbocharged multi-cylinder diesel engine.

A thermodynamic model will be discussed in this study for a single cylinder engine with its intake and exhaust systems simulating a turbo-charged V8 diesel engine. The basic parameters for the V8 engine are given in Table 1. The schematic layout of the intake and exhaust systems for the V8 engine is shown in Figure 1. The thermodynamic models for the SCE and the V8 engine are developed using the 1D engine thermodynamic simulation tool AVL BOOST. The BOOST model for the V8 engine was developed previously, which provides a ground for developing the thermodynamic model for the SCE. Because the interest of this study is the gas exchange systems, the boundary conditions for the intake and exhaust systems of the SCE are taken as the thermodynamic states of the charge after the EGR mixer and of the exhaust before the turbine (shown in Figure 1). The corresponding thermodynamic properties for the charge and the exhaust at these selected boundaries can be obtained from the BOOST simulations for the V8 engine.

Table 1. Basic parameters for the V8 engine

Bore	103 mm
Stroke	108 mm
Engine configuration	V8
Firing order	1 - 2 - 7 - 3 - 4 - 5 - 6 - 8
Compression ratio	16:1
Fuel injection equipment	Common rail (1800 bar)
Rated engine speed	3300 rpm
Rated engine power	300 kW

In the determination of the gas exchange systems for the SCE model, following criteria are considered: 1) the level of pressure fluctuations in the intake and exhaust systems should be within the lower and upper bounds of those simulated by the thermodynamic model for the V8 engine and patterns of the pressure waves should be similar; 2) the intake and exhaust flows of the SCE should be reasonably close to those of the V8 engine; 3) the cylinder pressures for the SCE should be reasonably close to those of the V8 engine under the same conditions for the valve timing, fuel injection, rate of heat release and in-cylinder heat transfer. Behavior of the pressure waves in the intake and exhaust systems depends primarily on the engine speed for a given design of the intake and exhaust pipeline systems. The intake and exhaust systems can be best tuned only at a single speed. Because the target vehicle for the V8 engine application may require that the engine to be operated most frequently in a speed range 2000 ~ 2200 rpm, 2050 rpm (corresponding to A speed of the ESC 13 mode for the V8 engine) is selected as the reference engine speed. The full load point at this speed (i.e., A100 load point) is selected for the gas exchange system design in order to gain good pressure wave patterns in the gas exchange systems at the selected engine speed. The 25% load point at the same speed (i.e., A25 load point) is selected for the comparison of changes in the wave patterns with the engine load. Details in the development of the intake and exhaust

systems for the SCE will be discussed in the following sections.

INTAKE SYSTEM DEVELOPMENT

Figure 2 shows the layout of the intake system for the SCE. It consists of an intake plenum, a tuning pipe, an intake receiver and two intake runners, associated with the tangential and helical ports of the V8 engine respectively. Because amplitudes of the pressure waves in the intake system are much smaller than the average intake pressures for a turbocharged diesel engine, in the layout of the intake system, the strategy is to limit intake pressure fluctuations within the lower and upper bounds of the V8 engine and with only limited tuning in the wave patterns. The intake receiver represents the intake manifold. The dimensions of the intake runners are carried over from those of the V8 engine. The intake plenum is an upstream component and thus it should be able to mitigate the influence of the supply pressure fluctuations on the downstream components. The cylinder for the SCE represents the cylinder 1 of the V8 engine. The volume of the intake plenum is taken to be 20 L, which was determined by the comparison of the mass aspiration into the engine cylinder calculated by the BOOST models for the SCE and the V8 engine at the selected engine speed.

The pressure fluctuations in the intake receiver influence the flows into the intake runners. The dimensions of the receiver should be determined from the consideration that the pressure patterns in the intake runners to be governed effectively by the tuning pipe. Various length/diameter (L/D) values for the entrance section and the dead-headed section of the receiver were investigated. The BOOST model did not detect a significant difference in length combination for the two sections of the receiver in the range $L/D = 0.5$ to 2 on the gas dynamics. A combination of $L/D = 0.5$ for the dead-head section and $L/D = 2$ for the entrance section was selected from the consideration of minimizing the pressure loss. The diameter of the receiver was selected also from the consideration of minimizing the pressure loss of the charge flow. The length for the receiver section between the two runners was determined by the distance between the two intake runners.

The tuning pipe between the intake plenum and the intake receiver governs the patterns of the pressure waves in the intake runners. Various values of the inner diameter d and length l for the tuning pipe were investigated with the BOOST simulations on the gas dynamics in the intake runners at the selected engine speed. The simulation results suggest that a tuning pipe with an inner diameter $d = 2.5$ in and $l/d = 10$ can generate wave patterns reasonably close to those in the intake system of the V8 engine.

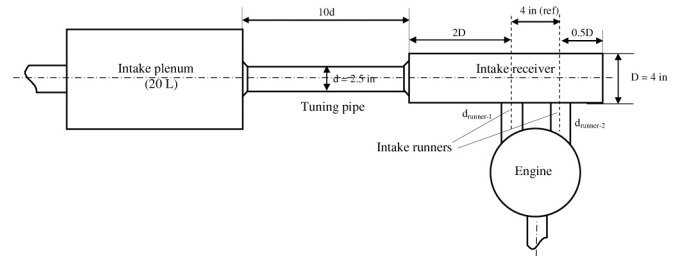


Figure 2. Layout of the intake system for the SCE.

EXHAUST SYSTEM DEVELOPMENT

Figure 3 shows the layout of the exhaust system for the SCE. To be in consistence with the BOOST model for the SCE, the pipeline from the exhaust plenum to the EGR loop and the valves for controlling of the exhaust back pressure are not shown in **Figure 3**. The exhaust system consists of five pipes in different lengths and diameters. These pipes form three branches: the exhaust leg, the exhaust pipe line that leads the exhaust to the exhaust plenum, and the interference pipe. As shown in **Figure 1**, the exhaust legs on each bank of the V8 engine can communicate with each other via pressures waves while the intake runners on each bank do not communicate with each other directly due to being separated by the intake receiver. Because the exhaust pipes are long and gas velocities in the exhaust system are much higher than those in the intake system, the dynamic pressures in the exhaust pipes have a high energy level. As a result, the exhaust wave from any cylinder can cause considerable pressure fluctuations in all the exhaust legs on the same bank (in this study, cylinders 3, 5 and 7 in the bank 1 of the V8 engine). Thus, to simulate the gas dynamics in the exhaust system for the V8 engine, the strategy for the layout of the exhaust system of the SCE must differ from that of the intake system.

Both the exhaust pipe and the interference pipe have two sections with different diameters and pipe lengths. The interference pipe is with one end dead-headed. The exhaust pipe and the interference pipe are so structured because compressive reflection waves can be generated at the sections with semi-blocking or fully blocking to the gas flow. In principle, the exhaust system for the SCE shown in **Figure 3** can possibly generate a V8-like pattern for pressure pulses in the exhaust leg in each of the engine working cycle. The diameters and lengths for the pipes in the exhaust system were tuned through the BOOST simulations on the gas dynamics in the exhaust system for the SCE with comparison of the gas dynamics for the V8 engine at the same engine speed. Similar investigations on the exhaust plenum were conducted as on the intake plenum. Because the exhaust plenum provides the back pressure to the exhaust flow for the SCE, the criterion for determination of its volume is that the pressure of the exhaust plenum should be as close as possible to the mean pressure in the exhaust pipe system in order to