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Study on the design of inlet and exhaust system of a stationary internal combustion engine

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Abstract

The design and operational variables of inlet and exhaust systems are decisive to determine overall engine performance. The best engine overall performance can be obtained by proper design of the engine inlet and exhaust systems and by matching the correct turbocharger to the engine. This paper presents the results of investigations to design the inlet and exhaust systems of a stationary natural gas engine family. To do this, a computational model is verified in which zero dimensional phenomena within the cylinder and one dimensional phenomena in the engine inlet and exhaust systems are used. Using this engine model, the effects of the parameters of the inlet and exhaust systems on the engine performance are obtained. In particular, the following parameters are chosen: valve timing, valve diameter, valve lift profiles, diameter of the exhaust manifold, inlet and exhaust pipe lengths, and geometry of pipe junctions. Proper sizing of the inlet and exhaust pipe systems is achieved very precisely by these investigations. Also, valve timing is tuned by using the results obtained in this study. In general, a very high improvement potential for the engines studied here is presented.

Keywords: Valve timing; Inlet pipe; Exhaust pipe; Junction; Natural gas engine; Efficiency

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1. Introduction

For proper sizing of an exhaust pipe system of internal combustion engines, the following parameters are to be optimized: diameter and length of the pipes; material, thickness and insulation of exhaust pipe system; geometry of pipe connections (junctions); and position of the necessary elements of the exhaust system such as turbocharger, catalytic converter, silencer etc. The engine intake and exhaust systems determine the engine operational behavior in steady and transient modes, the engine performance and the engine emissions regarding exhaust gas and sound.

The design of exhaust and intake systems has been studied by numerous researchers [1–3]. For a higher engine efficiency and for a better engine performance in transient operation, the energy losses in the intake and exhaust systems, including the valves, of an engine are to be kept at a minimum. As an important design parameter, valve timing has been studied intensively [4–10]. Valve timing is to be designed to optimize engine performance at the engine operating range. Especially, variable valve timing decreases the problems of valve overlap and is used to reduce fuel consumption as well as exhaust gas emissions.

This can be accomplished by optimizing the heat transfer rates and pressure losses, particularly in the exhaust system, since higher temperatures and very complex gas flow phenomena occur in the exhaust system. The energy losses and flow instabilities in a pipe system occur particularly in pipe junctions. The energy losses in pipe junctions can be represented in engine cycle simulation by using pressure loss coefficients depending on the geometry of the junction, flow direction and mass flow rates. Accurate values of the pressure loss coefficients can be obtained experimentally as well as by analytical methods, for example one dimensional flow theory [11,12]. Kuo and Kalighi [13] performed a study to obtain flow loss coefficients for T shaped pipe junctions used in internal combustion (IC) engine exhaust systems numerically and experimentally. They showed that the flow loss coefficients are only mildly dependent on the cross-sectional shape. Klell et al. [14] give an alternative method to compute flow in pipe junctions. Their method is based on well known conservation laws such as mass, momentum and energy.

Turbocharging plays a crucial role to utilize exhaust gas energy efficiently. In order to increase the efficient use of exhaust gas energy, first, the gas is to be transported with minimum energy losses from the cylinders to the turbine. Then, this gas energy is to be converted at the turbine into mechanical work in the best possible way, which is needed by the compressor. Meier et al. [15] describe the "transmission or manifold efficiency" as the ratio of the exhaust gas energy given to the exhaust turbine to the exhaust gas energy at the cylinder exit.

Optimization of the exhaust pipe system aims to obtain higher transmission efficiencies in the engine operation range. Apart from obtaining higher transmission efficiency, by proper design of the engine exhaust system and by matching the correct turbocharger to the engine, the best engine overall performance can be obtained.

This paper deals with investigations to design the inlet and exhaust systems of a stationary natural gas engine family. In the framework of a detailed research and development project in cooperation with the university and industry, a gas engine series with 12, 16 and 20 cylinders, which is used in combined power plants, has been optimized regarding power, efficiency and emissions. Zero dimensional process calculations as well as one and multi-dimensional flow calculations are used for optimizing the gas exchange of these gas engines. Based on a precise comparison between measurements and calculations, extensive examinations for optimizing the gas exchange of V12,