

ABSTRACT

In urban traffic, most vehicles operate under part-load conditions, where spark-ignition (SI) engines regulate load using a throttle valve. Partial throttle openings, however, create a pressure drop in the manifold intake, resulting in pumping losses during the gas exchange process. Conventional camshaft-driven valvetrains employ a fixed cam profile, making valve events solely dependent on crankshaft speed. Consequently, the timing, duration, and lift of valve operation remain constant across the entire operating range, leading to suboptimal performance at both low and high speeds. This work attempts to address these limitations and enhance the gas-exchange process in combustion engines by designing an electronically controlled valve actuation system.

An electro-pneumatic-based variable engine valve actuation system is proposed. A comprehensive mathematical theory for an electro-pneumatic variable valve actuation (EPVVA) system is developed, which models the thermo-fluid-dynamic and applied-mechanical aspects of the actuator cylinder and engine valve system. With the help of mathematical theory formulated, the evolution of a design matrix map of a double-acting EPVVA is quantified for the engine speed varying up to 5500 rpm. After assessing the relative merits and demerits of the double-acting EPVVA system, the development and design optimization of a single-acting EPVVA system for a Camless Spark Ignition Engine is undertaken. This involved the development of mathematical theory, experimental rig, characterization methods and design optimization procedures. The experimental test rig consists of a pneumatic actuator, fast-switching solenoid valves, a microcontroller, a high-speed camera and an air reservoir. The electronic control of valve event characteristics, such as peak lift, valve open duration, and initiation of valve open/closure, is achieved by systematic variation of the pulse-widths and the activation timing of solenoid valves. The high-speed photographic method was used for measurement of the valve actuation profile. Several experimental measurements are taken to validate mathematical theory and to characterize delays in valve actuation as well as cycle-to-cycle variations in valve events. Essential features of the valve actuation profile, such as electrical and mechanical delays during charging and discharging, expansion and overshoot, are characterized. The coefficient of variation in peak lift and valve open duration in multi-cyclic operation is found to be less than 3.2%. A design optimization algorithm is developed to obtain the optimal

design of a single-acting EPVVA system that can be retrofitted to an existing cam-based Gasoline engine. The algorithm uses the developed mathematical theory and a binary-coded genetic algorithm (BCGA) to optimize the design of the EPVVA system. It was found that the optimized EPVVA system can achieve improved volumetric efficiency (up to 63% at 1000 rpm) compared to the cam-based valve actuation system.

The control system is designed using a model-based approach in MATLAB Simulink to integrate the optimized EPVVA system with the engine. The control system design incorporates an engine valvetrain model and a valve actuator model, both of which operate with the control algorithm in real time. The verification of the control algorithm is conducted through model-in-loop (MIL), software-in-loop (SIL), and processor-in-loop (PIL) simulations. An in-house experimental setup is developed to experimentally evaluate the performance of the control algorithm when integrated with an engine. The experimental setup consists of a SI research engine, an alternating current dynamometer, the port-fuel injection system, an open type of electronic control unit (ECU) and the EPVVA system. The control algorithm is then deployed onto a C2000 microcontroller that runs in tandem with the engine ECU to control the valve actuation. The computations of the control algorithm are validated with the engine ECU through engine hardware experiments conducted offline. Closed-loop experiments are conducted to evaluate the controller's performance under varying engine speeds and valve events. Several fail-safe logics are incorporated in the control algorithm to prevent engine valve piston interference and to improve the reliability of valve actuation during engine experiments. The performance of the EPVVA system is then evaluated by retrofitting it onto a conventional cam-based engine. The engine experiments were conducted at low and medium loads (brake mean effective pressure (BMEP) varying from 2 to 5 bars) at various engine speeds (700 to 1500 rpm) in both the cam-based and camless engines. The effect of varying the valve timing on the gas-exchange process is analyzed experimentally. The experimental results showed an improvement in brake specific fuel consumption (BSFC, maximum 10.8%), decreased pumping losses (maximum 37%), and improved volumetric efficiency in the engine retrofitted with the EPVVA system. The methodology of throttle-less load control and its effect on the gas-exchange process are also analyzed.

Keywords: Camless Engine, Electro-Pneumatics, Variable Valve Actuation, Control System Design, Pumping Losses, Throttle-less load control