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Research Paper

Effects of electromagnetic intake valve train on gasoline engine intake charging

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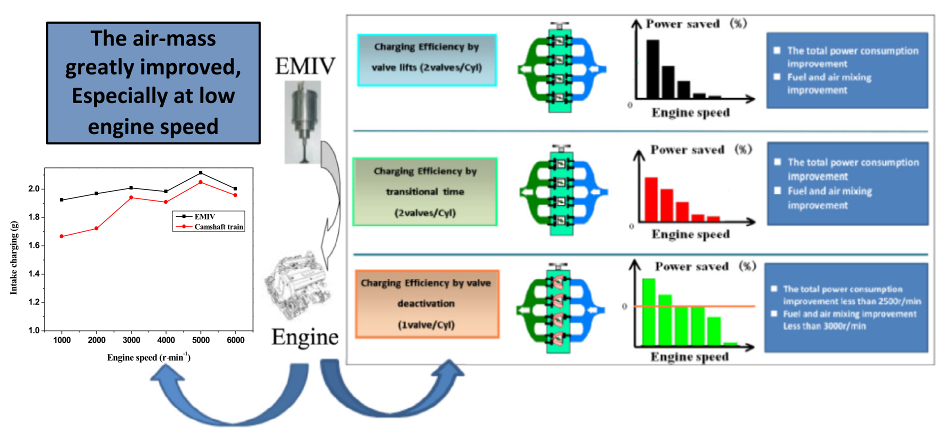
HIGHLIGHTS

- The intake charging will be close to the extreme of the engine by application of the EMIV.
- At low engine speed, lower valve lift needs less power consumption but less air decreased.
- Modifying the transitional time will have higher efficiency for charging.
- The efficiency of charging will be greatly improved by signal valve mode when the engine speed is less than 3000 r/min.

GRAPHICAL ABSTRACT



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ABSTRACT

Electromagnetic intake valve train (EMIV) is capable of regulating the intake valve control parameters such as intake phase, valve lift and transitional time at any given operational condition, which provide an effective way to improve the performance of engine. So the engine model was established to research the intake quantity influenced by intake valve variables such as intake phase, valve lift, transitional time and single/double mode, then the maximum of intake charging and the related control parameters under different engine speeds were obtained; combined with power consumption of the EMIVs and pumping loss, the control parameters with higher efficiency were obtained to satisfy the intake quantity. The results show that by EMIVs, the intake changing of the engine can be significantly improved, especially at lower engine speed which the increase can be reached by 18.3%; what's more, by optimized valve control parameters, the power consumption in the air charging process can be reduced under the same intake charging, for example, the power consumption of single valve model will decrease by 35.9% compared with the double valve model at 2000 rpm.

1. Introduction

Today people pay more attention to energy-saving and environmental protection, which are daunting challenges to automotive industry. Over the past 10 years, mechanical variable valve-trains were greatly developed, such as variable valve timing (VVT) and variable valve lift (VVL), and have been large-scale application on automotive [1,2], but these systems cannot still meet the fast-growing needs of low consumption and high efficiency (engines). To further improve engine's performance, some big automotive companies and research institutes moved their attention back to camless technology, especially electromagnetic valve train.

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The electromagnetic intake valve train (EMIV) is a fully variable valve technology; the control parameters such as the intake phase, valve lift, transitional time and numbers of working valves per cylinder can be flexibly modified [3–6] along with the engine condition; what's more, the engine load can be controlled by adjusting the valve control parameters instead of throttle valve, and the power loss by [7,8] throttling can be much more reduced, so the EMIV technology becomes one of the important research directions in the future engine development.

The research on EMIV is mainly concentrated on the control scheme and strategies, but there are few mature achievements about the engine's extreme intake charging and the costs to achieve extreme.

In this paper, the maximum intake charging under different engine speeds was discussed first, and then the optimal parameters of EMIV were discussed by contrasting the EMIV's power consumption and pumping loss. These studies can provide a basis for the application of the EMIV.

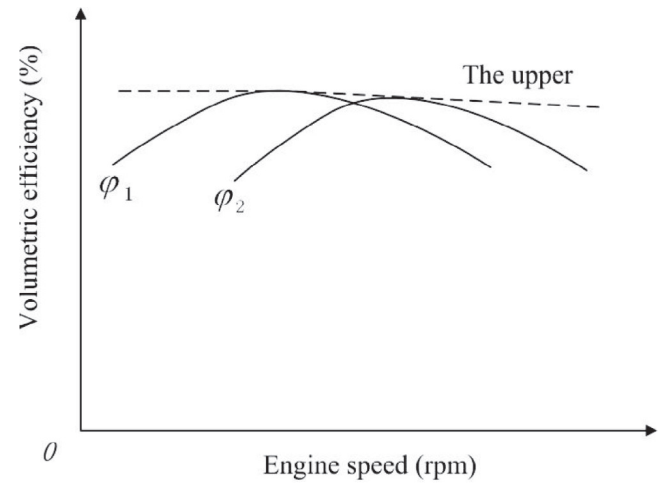

Fig. 1. Volumetric efficiency for different IVC timing.

2. The principle of EMIV to improve intake charging

2.1. Mathematical model for charging

Mass flow of engine inlet can be calculated by isentropic port equation 1; the port flow efficiency can be obtained by steady flow test equipment.

$$\frac{dm}{dt} = A_{eff} \cdot p_{o1} \cdot \sqrt{\frac{2}{R_o \cdot T_{o1}}} \cdot \Psi \tag{1}$$

The effective flow area in equation 2 is decided by the flow coefficient:

$$A_{eff} = \mu\sigma \cdot \frac{d_{vi}^2 \cdot \pi}{4} \tag{2}$$

The air charged into cylinder can be obtained by the instantaneous flow integrated. Then the engine volumetric efficiency can be obtained by equation 3.

$$\eta_v = \frac{m_1}{m_s} = \left(\frac{P_a}{P_s}\right) \cdot \left(\frac{T_s}{T_a}\right) \cdot \left(\frac{V_a}{V_S}\right) \tag{3}$$

2.2. Theories of improving intake charging by EMIV

2.2.1. The intake valve closed (IVC) angle

The traditional camshaft valve train is designed to satisfy the engine performance at high speed; the intake control parameters are invariable. So at lower engine speed, the intake valve closed timing (IVC) is too late that some air will flow out of cylinders with the air flow velocity decline, so the air-mass will be decreased. Therefore regulated IVC with the engine speed can improve the engine's intake charging [9], as shown in Fig. 1.

The volumetric efficiency will be improved with IVC φ_1 at lower engine speed, which IVC φ_1 is less than φ_2. Therefore, in order to make full using of the intake air flow inertia, increasing IVC angle with the engine speed increasing can get a higher volumetric efficiency.

2.2.2. The intake valve opened (IVO) time

On full load, the pressure in cylinder will decrease with the engine speed increasing. If the IVO angle opened too early at lower speed, some gas will flow into the inlet pipe because of deferential pressure, which will cause some charging resistance that the P_a in equation 3 diminished; what's more, T_a will rise because inlet air is heated by exhaust gas. These will cause decreased volumetric efficiency. Therefore the adjustment of IVO timing can also improve extreme intake charging.

2.2.3. The valve lift and transitional time

From equation 2, the effective flow area of intake valve fully opened will be increased with higher valve lift, and the effective flow area of opening and closing can be increased with shorter transitional time. So the intake quantity can also be improved by adjusting the valve lift and transitional time.

2.3. Power consumption improved for engine with EMIV

In a traditional cam engine, the energy losses of valve trains are mainly consumed in various frictions. Instead, the camless engine equipped with EMIVs can decrease the frictions to a great extent. But the working of actuator is also driven by electric energy, which will cause energy losses in the process of electromechanical energy conversion. With variable parameters, intake valve has different motions, which would mainly affect the power consumption of valve trains and pumping works, both of them have effects on the break mean effective pressure of engine. So in the paper, the relation between valves' power consumption and pumping work is mainly mentioned.

3. Experimental platform and causational model for EMIV engine

In this paper, the EMIV developed by ourselves is a camless system [10–12], the control parameters of which can be fully variable based on moving coil linear actuator. The moving parts have longer life and higher reliability compared with the common double electromagnet structure [7,13].

3.1. Experimental platform

Experimental platform is designed to obtain the power consumption of valve train under variable valve events and to verify the accuracy of theoretical method, as shown in Fig. 2.

In the experiment system, a fixed-point TMSECS320F2812 digital signal processing (DSP) with a clock frequency of 150 MHz is chosen as the digital controller. While closed-loop Hall-effect current sensor (TBC10SY) and voltage sensor (SMIV ±50DCE) are used to measure EMIV's input current and voltage, for precise laboratory measurement a magneto resistive linear displacement sensor is used to

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