Design and Analysis of an Electro-Hydro-Mechanical Variable Valve Actuator for Four-Stroke Automobile Engines

Tam Kuok San

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for Four-Stroke Automobile Engines

by

Tam Kuok San

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Address: Pátio de Chôn Sau No. 24 R/C
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E-mail: coopertam@gmail.com

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Abstract

Design and Analysis of an Electro-Hydro-Mechanical Variable Valve Actuator for Four-Stroke Automobile Engines

By Tam Kuok San (M-A0-6210-7)

Thesis supervisor: Prof. Wong Pak Kin

Department of Electromechanical Engineering, Faculty of Science and Technology

In modern four-stroke automobile engine technology, variable valve timing and lift control offers potential benefits for making a high-performance engine. A novel and simple electro-hydro-mechanical fully variable valve actuator (EHMFVVA) for engine valves is introduced. Just like the conventional mechanical variable valve actuators, a camshaft is still used the design; however, it is employed to provide input hydraulic pulses to drive the engine valves cyclically. The output valve profile is controlled electronically by a common proportional pressure relief valve, and hence Late-Valve-Opening + Early-Valve-Closing + Variable-Max-Valve-Lift can be achieved. The construction of the mathematical model of the variable valve system and its dynamic analysis are also presented. Experimental and simulation results show that the novel electro-hydro-mechanical variable valve actuator can achieve fully variable valve timing and lift control without using complex control systems. Incorporated with the proposed system, the performance of four-stroke engines at different speeds and loads will be significantly increased.

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NOMENCLATURE

A_1 Cross-section area of the master-cylinder piston (m^2)

A_2 Cross-section area of the valve-cylinder piston (m^2)

A_c Cross-section area of check valve orifice (m^2)

A_r Cross-section area of pressure relief valve orifice (m^2)

C_d Discharge coefficient of valve orifice

C_{tp1} Leakage coefficient of the master cylinder ($m^3/Pa\cdot s$)

C_{tp2} Leakage coefficient of the valve cylinder ($m^3/Pa\cdot s$)

D Tappet lift (m)

d Hydraulic pipe diameter (m)

d_p Poppet valve diameter (m)

F Load on poppet valve (N)

F_0 Preload in the master-cylinder spring (N)

F_{co1} Sliding friction on the master-cylinder piston (N)

F_{co2} Sliding friction on the valve-cylinder piston (N)

F_{pre} Preload in valve spring (N)

F_{r1} Friction force on the master-cylinder piston (N)

F_{r2} Friction force on the valve-cylinder piston (N)

$F_{st1\max}$ Maximum static friction force on the master-cylinder piston (N)

$F_{st2\max}$ Maximum static friction force on the valve-cylinder piston (N)

ΔF_1 Resultant force on the master-cylinder piston (N)

ΔF_2 Resultant force on the valve-cylinder piston (N)

g Acceleration of gravity = 9.81 m/s^2

K_g Stiffness of valve spring (N/m)

K_1 Stiffness of the master-cylinder spring (N/m)

K' Gain of proportional pressure relief valve (Pa/V)

l_2 Length of hydraulic pipe (m)

m_1 Mass of the master-cylinder piston (kg)

m_2 Mass of the valve-cylinder piston (kg)

P_0 Set pressure (Pa)

P_1 Operating pressure in the master cylinder (Pa)

P_2 Operating pressure in the valve cylinder (Pa)

P_L Residual gas pressure in combustion chamber (Pa)

ΔP Pressure drop along the pipe of the valve cylinder (Pa)

Q_1 Hydraulic flow generated by the master cylinder (L/min)

Q_2 Hydraulic flow into the valve cylinder (L/min)

Re Reynolds number

r Base circle radius of input cam (m)

V_1 Initial volume of the master cylinder (m^3)

V_2 Initial volume of the valve cylinder (m^3)

v_2 Flow velocity in the pipe of the valve cylinder (m/s)

X_1 Cam lift (m)

X_2 Piston displacement of the master cylinder (m)

X_3 Piston displacement of the valve cylinder (i.e. displacement of engine poppet valve) (m)

α Camshaft angular displacement (rad)

β_e Bulk modulus of hydraulic medium (Pa)

θ Crank angle (rad)

λ Hydraulic flow drag coefficient

μ Proportional valve control signal (V)

ν Kinematic viscosity of hydraulic medium (m^2/s)

ρ Density of hydraulic medium (kg/m^3)

ω Angular frequency of camshaft (rev/s)

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