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A NEW APPROACH FOR VARIABLE VALVE ACTUATION (VVA) MECHANISM TO ENHANCE ENGINE PERFORMANCE.

MR. LAXMAN KUMAR PANDEY[1], PROF. DHARM DUTT[2], PROF. S. P. SINGH[3]

1. Research Scholar, Indian Institute of Technology Roorkee
2. Professor, Indian Institute of Technology Roorkee
3. Professor, Indian Institute of Technology Roorkee

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Abstract: A system for controlling the operational mode of an engine includes valve and injection events in which the engine comprises of plurality of cylinders having an inlet and exhaust valves, an injector and a chamber. The high demands on precision and dynamics of hydraulics drives result in new requirements of valves. The performance of valves depends primarily on the dynamics of actuators nowadays. In this paper we have designed a new approach of variable valve actuation by using fast and stiff electromagnetic actuators as valve drives. The electromagnetic valve actuator system was basically designed for a diesel engine and a personal computer based engine control system (Electronic control unit) was used which used to manage the fueling, ignition, throttling and intake/exhaust valves control functions. Also the advantages that electromagnetic valve actuators offer for valve characteristics concerning disturbances and the engine performance and emissions were studied throughout.

Keywords: FEVAD, VVT, Electronic control valve.

Corresponding Author: MR. LAXMAN KUMAR PANDEY

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INTRODUCTION

Automotive electrical systems today are moving towards higher power requirements. The introduction of this standard, coupled with recent advances in power electronics, sensors and microprocessors, has led to several innovations in automotive systems. Many of these innovations significantly increase fuel economy, and some involve the replacement of automotive mechanical systems with electrical systems. Of particular relevance, the new voltage standard has made the electrification of internal combustion (IC) engine valves a technically and economically viable innovation. In conventional IC engines, engine valve displacements are fixed relative to the crankshaft position. The valves are actuated with cams that are located on a belt-driven camshaft, and the shape of these cams is determined by considering a trade-off between engine speed, power, and torque requirements, as well as vehicle fuel consumption. This optimization results in an engine that is highly efficient only at certain operating conditions. Instead, if the engine valves are actuated as a variable function of crankshaft angle, significant improvements in fuel economy up to 21% can be achieved. In addition, improvements in torque, output power and emissions are achieved. Internal combustion engines in which both the duration (how long each valve is opened or closed) and the phase (how each valve profile is shifted with respect to some nominal valve profile) of the valves can be controlled are said to have variable valve timing (VVT). VVT can be achieved using fluidic system with electromagnetic actuation systems. In this paper, the focus is on an electromagnetic actuation system. With VVT alone, a 21% improvement in fuel economy can be achieved. Further more, if the lift (how much each valve is opened) of the valves is controlled, another 21% improvement can be gained. Currently, the most advanced VVT system is an electromagnetic engine valve actuation system that includes a valve-spring system coupled to two electromagnetic normal-force actuators. Although these actuators are well-suited to holding the engine valve open or closed, there are some fundamental design challenges posed by this actuation system, especially in the area of controller design. In order to solve the significant design challenges associated with electromagnetic normal-force actuated VVT systems, we have proposed a new approach of variable valve actuation (VVA) by using a unique Fluid Electromagnetic Valve Actuation Drive (FEVAD) incorporating a nonlinear mechanical transformer for a diesel engine. In this paper, we describe the FEVAD and the implications for the design of its power electronics and controllers. We will discuss these implications and describe the design and construction to validate the concept of this FEVAD.

Main Section

1. *Objective of the paper*

A great deal of development know-how has to be incorporated into the design of the Fluid Electromagnetic Valve Actuator Drive (FEVAD) to attain certain objectives. The most important criteria of this design and manufacturing process are listed below:

- Reducing the weight of the moving parts.

- Preventing forces which exert a negative influence on the dynamic performance of the valves.
- Increasing the performance of the engine by faster valve response and improved actuating dynamics.

2. DESIGN METHODOLOGY

The basic component of the Electromagnetic Valve Actuator Drive (FEVAD) is a dense fluid and inside it electromagnet, a close spring, an armature, an armature guidance system and a hydraulic damper. The armature resides above the electromagnet pole face, such that energizing the electromagnet will pull the armature in the direction of the energized electromagnet. Note that electromagnet can only attract the armature, repulsion is not possible. The armature guidance system allows for motion of the armature above the electromagnet such that the surface of the armature is parallel to the surface of the electromagnet when the surfaces make contact. The force of attraction ***(F_m)*** between an electromagnet and an armature is inversely proportional to the square of the distance between them

$F_m=k*1/(r*r)$

Where k is some constant. Because the electromagnet force decreases with distance from the armature, the electromagnet is best suited for applying force when the armature is close to the electromagnet. An electromagnet which, by itself, could force open an exhaust valve would be far too large to be practical. Therefore, fluid pressure used to push the armature away from the electromagnet.. When the electromagnet is energized, the armature is pulled toward the electromagnet. To close the valve, the electromagnet is de-energized and the lower (close) spring pushes the armature towards the closed electromagnet. When de-energising the electromagnet, the armature will begin to oscillate in simple harmonic motion at a frequency determined by

$F = w/ (2*3.142)$

Where w is angular frequency whose magnitude is equal to the square-root of spring stiffness constant (k) to the total moving mass comprised primarily of the armature, approximately half the combined spring mass, and the valve. The transition time for the valve to open or close is approximately determined by

$t =1/2f$

Assuming that damping is negligible, or is countered by the hydraulic damper which works on the principle of viscous damping.

The static force requirement for the electromagnet can easily be determined from a free body diagram. The result is approximately

$Fm = F_{spring} = Kt_{otal} * (lift/2)$
Where $K_{total} = K_{top} + K_{bottom}$

Electromagnetic force is proportional to electromagnet pole face area, so from the above expressions, several observations can be made.

- To decrease transition time either stiffer springs or a lighter mass are required.
- To increase lift and keep transition time constant requires a larger electromagnet force, which in turn requires a larger and heavier armature, which subsequently requires heavier and stiffer springs.
- Moving mass should be kept to a minimum.

The above equations may not hold true for valves operating against large residual exhaust pressures. The deviation will depend on the magnitude of required opening force.

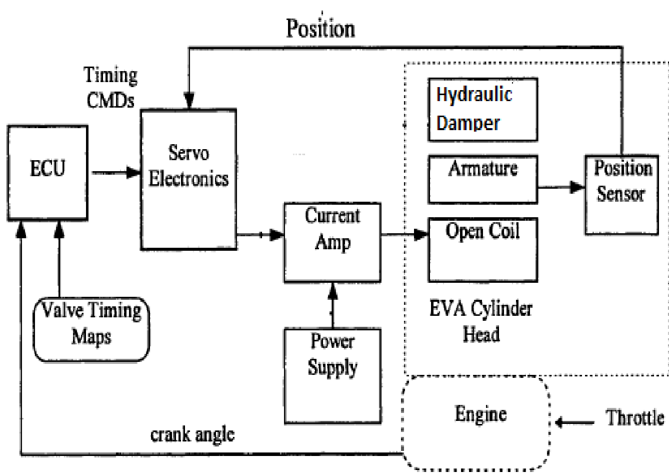

Figure 1: FEVAD Electronics Configuration

Figure 1 illustrates the basic FEVAD electronics configuration. The Electronic Control Unit (ECU) generates valve timing commands corresponding to crank angles defined in two dimensional tables called maps. Figure 2 is an example of a valve timing map for intake open angle which is fed into the ECU. Armature positions are monitored by an eddy current sensor, these position signals are then send to the servo electronics box, along with the ECU commands. The servo electronics process this information and generate the appropriate actuator coil current commands for the current amplifier which drive the electromagnet coil.

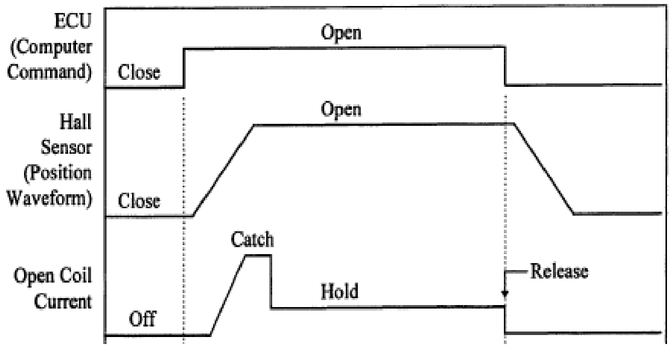

Figure 2: FEVAD Example Wave forms - Position and Current vs. Time

Like the above valve time map, any map can be fed into the ECU based on design and demand of the manufacturer. Also the valve-lift vs. time graph can be generated and fed into the ECU as per the requirement.
Figure 4 shows an example of the Valve-lift % vs. Time graph.

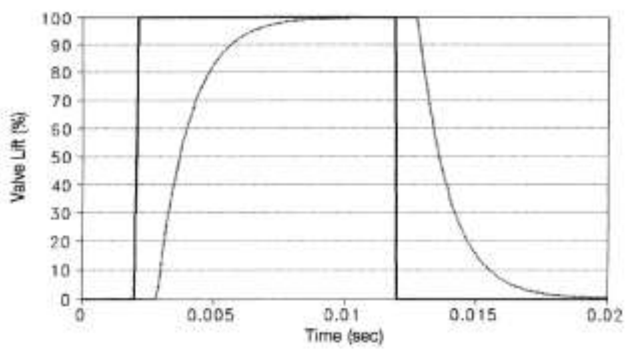

Figure 3: Valve-lift % vs. Time

3. ENGINE PERFORMANCE

The FEVAD is designed to operate on a diesel engine. Since petrol engines have a high engine speed, so running the FEVAD as very high speeds will lead to excess vibrations which cannot be compensated by the hydraulic damper. Therefore diesel engines are selected which runs a at lower engine speed than the petrol engines. Since this is entirely a cam-less drive, the working of FEVAD entirely depends on the ECU. The ECU controls opening and closing of the valves with high accuracy and precision allowing perfect air intake and exhaust. This directly affects the volumetric efficiency of the engine thereby increasing torque and Brake Mean Effective Pressure (BMEP) of the engine. Also the engine can be balanced better since weight of the engine gets reduced and a lighter engine is available.

4. EMISSION

The emissions benefits of Exhaust Gas Recirculation (EGR) are well documented by each manufacturer, but the method for achieving and controlling the desired EGR rates create problems on the engine and force the engine development engineer to sacrifice efficiency and performance. With the FEVAD system, since the exhaust valve events can be varied, the residual gases (or EGR) trapped within the cylinder could be controlled directly. This would eliminate the need for designing a high or low pressure EGR loop to introduce the exhaust back into the engine intake. This technique would likely represent the best approach for transient and true "cycle-by-cycle" control of residual fraction (or EGR).

CONCLUSION

A successful design of a Variable Valve Actuator was obtained using Computer Aided Designing (CAD) Software. The product was validated and benchmarked on different basis. It meets all the requirements of demand providing faster response, better control, devoid of mechanical cams, engine weight reduction and several other advantages. These advantages give FEVAD a superior edge of cam drives. Also better engine performance was obtained without increasing engine emission. Future research work includes building a prototype and testing of the FEVAD apparatus, confirmation of the benefit of FEVAD, and the design of more optimal controllers for the system, including but not limited to controllers that will minimize the power consumption of the system.

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