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Embodiment of Electromagnets over Conventional Cams

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ABSTRACT : Consumption of fuel has become a vital issue in all internal combustion engine design these days, as the fuel prises are rising up high and high each one of us wants such a type of automobile which can saves ones money while riding up on a hill or when any one of us is standing up on a jam or on a red light or if we are moving individually in a three/four/six/eight cylinder automobile and we don't want to boost up all the cylinders, then who can save this problem ? It's only camless engine which can solve our problem. Methods for increasing the efficiency of four stroke SI engines at part load conditions and their potentials for practical use were investigated in [1] where it was found that most promising methods to decrease the fuel consumption are stratified charge and variable displacement engines. Modelling and sensor less control of electromagnetic valve actuator with the objective of minimizing energy consumption was conducted [2]. We can save 50% fuel consumption which has been achieved by Toyota hybrid system, which is there in mass production since 1997 [3]. This data was achieved when they combined 2 permanent magnet motors and a newly developed engine that is optimised in terms of its displacement and heat cycles. In [4] previous research regarding prototype and production gasoline direct injection engines worldwide was revived as to fuel economy for areas requiring further development

Keywords : Camless, Electromagnetic valve actuator, permanent magnet, heat cycles, prototype.

I. INTRODUCTION

As we all know that inlet valve lift ranges from 1 mm to 7 mm with 1 mm increment and inlet valve closing timings ranges from 60° to 280° with 20° increment of crank angle. We assume that inlet valve opens at TDC *i.e.* at 0° angle. As use of cam offers a compromise between maximum power and fuel economy which had lead to the concept of camless engines where both parameters like maximum efficiency and power can be achieved simultaneously. History shows that idea of this very engine has its origin as early as on 1899. During that time it was suggested that independent control of valve actuation could result in increased engine power. The research on control of solenoid is crucible since precision and response is a limiting factor for developing reliable camless valve actuator

Why Camless Engine ? One main reason behind the extra fuel consumption in IC engine at part load condition is, at the throttle body of intake manifold there is flow restriction due to which pumping losses increases. if we eliminate the throttle valve and by controlling the amount of air which enters the cylinder then we can achieve the target of fuel consumption and this we can get when we can regulate the opening and closing of intake valve motion, and we can have this type of motion only in that engine which do not have any camshaft i.e. camless engine. In these types of engine the inlet and outlet valve motion is controlled electronically. For this system we need a very and very precisely controlled Electronically Controlled Unit (ECU). The system capable of monitoring cylinder air charge and minimizing pumping losses. By tracking the cylinder air charge torque demand could be compromised on the contrarily by minimizing pumping losses we are capable of having control on fuel consumption. In a Camless engine, the intake valve motion is controlled electronically, and a control system design is needed with two main objectives, namely, cylinder air charge tracking and minimizing pumping losses. Cylinder air charge tracking will satisfy the driver's torque demand, whereas minimizing pumping losses will improve fuel economy.

Basic Valve Operating Mechanism: As we all know that the valve operating mechanism consist of :Rocker arm, Spring retainer,Springs,Valve guide,Valve,Clearance adjustment, Push rod, Valve lifter/Valve tappet/Cam follower, Camshaft and Cam shaft drive. The Cam is one of the most important members of valve operating mechanism. Cam shape or contour plays major role in operating characteristics of engine. Shape of the lobe determines : when the valves has to open, how far they have to be opened and how long they have to remain open and all these determines the amount of valve overlap. The cam controls the amount of air that comes in.

Conventional valve train profiles background: An IC engine valve's kinematics profiles (such as valve position versus time, valve velocity versus time, and so on) are of fixed shape and these are timed relative to the engine crankshaft position. From a control point of view, we say that the engine valves are not controllable. If instead, we could independently control the phase, lift and duration, of the valves, we can get a tremendous improvement in parameters like: Emissions, Efficiency, Maximum power, and Fuel economy would be seen. Although the mechanical design of engines is simple, its design compromises between the efficiency and maximum power of the engine [5]. However, any variable valve actuation system must be able to offer a variable valve profiles without compromising the essential characteristics of a conventional IC engine valve profile [6]. The average power losses associated with driving the engine valves is approximately 3 kW for 16 valves in a 2 : 0 L, 4 cylinder engine at 6000 rpm engine speed and wide open throttle. Fig. 1 shows different kinematics variables for a conventional IC engine valve along with individual kinematics variable

There are a few important points to make about Fig. 1.

1. Although the valve inertial power is very large, it is also regenerative after an initial input of inertial power, and this inertial power is regenerated continuously. A spring is used to store the initial required energy and then the energy is transferred cyclically to the engine valve and cam. To be a competitive technology, any variable valve actuation system must be able to provide this large inertial power economically [7] [8].

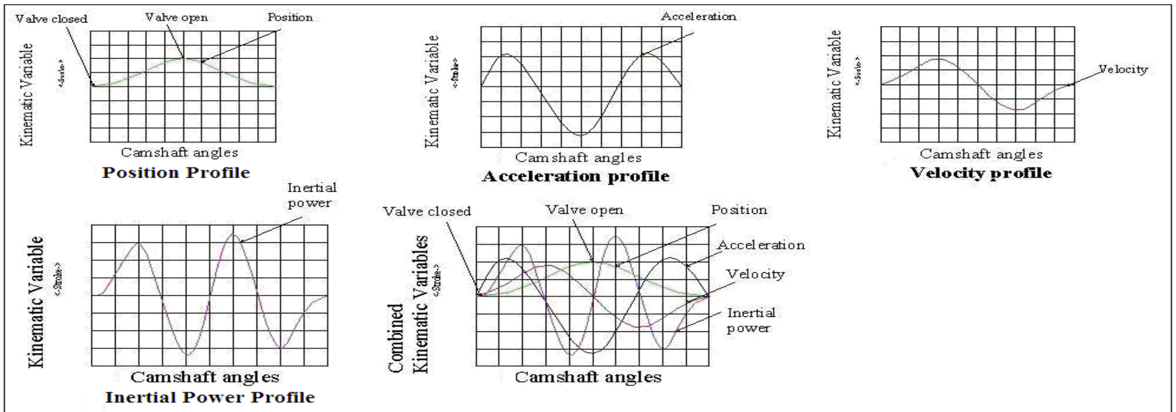


Figure-1 Conventional IC Engine Valve Train Profile

2. The seating velocity of the valve is small (less than 3cm/s at 600rpm engine speed, and less than 30 cm/s at 6000 rpm engine speed),which allows for the so-called soft landing of the valve. In order to prevent excessive wear of engine valves, any variable valve actuation system should allow for the soft landing of the valve.

3. An engine valve's kinematics profiles are inherently smooth. From a mechanical design perspective, discontinuities in valve kinematics profiles can generate undesirable impacts/losses and acoustical noise.

But with an Electro-magnetically-driven variable valve timing system (VVT), one can independently control the phase and duration of the engine valve profiles, and carry out variable engine displacement (where certain cylinders in the engine are deactivated). In these VVT systems, the valve can be held in the open or closed positions for a variable time period (called the holding time), and it transitions from one end of the stroke to the other in the transition time.

Prototype Electro-magnetically actuated VVT systems have been proposed by several companies in the automotive industry, the first being proposed and patented by FEV Motorentechnik [9], [10]. Other companies that have worked on this technology are: BMW [11], [12], GM [13], Renault [14], [15], Siemens [16], [17] and Aura [18].

Control challenges to achieving soft landing with normal-force actuators.While discussing about the soft landing of valve which is one of the other desirable characteristics for VVT systems: the valves should reach either end of the stroke with very small velocity and acceleration. However, there are substantial control challenges to achieving soft landing with normal-force actuators which are described below.

1. Since the normal-force actuators are unidirectional, it is very difficult to decelerate the valve as it approaches an end of its stroke. To arrive exactly at the end of the stroke with exactly zero velocity (defined as perfect soft landing), the receiving-end actuator must do exactly as much work as was done against friction and gas force over the entire transition. If the actuator does not do this much work, the valve will stop before the end of the stroke, and will be driven away again by the spring. If the actuator does any more than the exactly correct work, the valve arrives at the end of the stroke with non-zero velocity, and impacts the valve seat.

2. The electromagnetic actuators have a nonuniform force constant, making it difficult to apply enough force to the valve when it is close to the equilibrium point of the system. Thus, it is difficult to counteract the effects of the gas force disturbance on the system.

Main characteristics of electromagnetically-driven VVT systems: Most electromagnetically-driven VVT systems have emulated one of the main characteristics of conventional IC valve profiles and i.e. to regenerative inertial power. At the centre of these actuators is a valve-spring system, where an engine valve is coupled to two springs (with the same spring constant) as shown in Fig. 2.

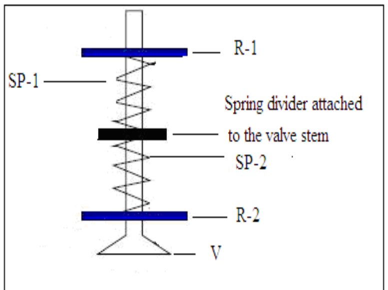


Figure-2 An Conventional Engine Valve Spring System

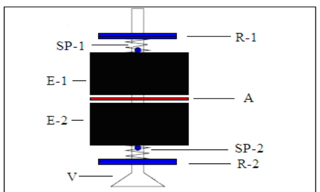
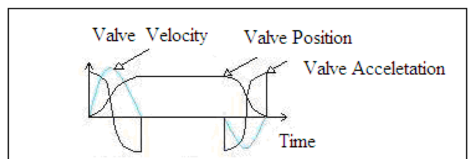


Figure-3 A Normal Force Actuated Valve Spring System

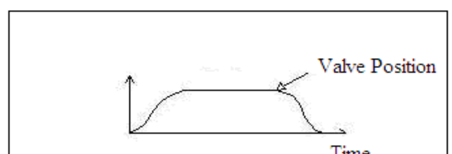
The equilibrium position for this mass-spring system is in the middle of the valve stroke. Such type of system has: An inherent natural frequency (η), Mass (m), Effective spring constant (k), and damping ratio (ζ) Assuming that there was no damping, an initial displacement of the valve in the direction of either spring would result in sustained oscillations of the valve at the system's natural frequency $(\eta = \sqrt{k}/m)$. In the ideal frictionless case, considering only the dynamics of the valve, the Electro-mechanical actuator for the valve-spring system only has to be able to hold the valve at either end of its stroke. In reality, due to gas forces in the engine, especially on the exhaust valves, additional work is required to reject the gas force disturbance. In addition, as the spring forces increase linearly with valve displacement, these forces are largest at the ends of the stroke, making it difficult to hold the valve in the open or closed position without using a large holding force, and thus a lot of electrical power [7].

Basic model for controlling the valve-spring system: As seen in the above given Fig. 3 the basic model consists of: Valve-[V], Two fixed reference frame [R-1] and [R-2], Two springs-[SP-1] and [SP-2], One Armature-[A], Two Electromagnets/Solenoids-[E-1] and [E-2] One to hold the valve open and One to hold the valve closed [9], [10].Each Electromagnet/Solenoid/Actuator exerts a unidirectional normal force, and thus, the system employs two normal force actuators but these actuators have a nonuniform force constant because the force exerted by these actuators is proportional to the square of the current input, but decreases as a function of the air gap between the actuator and the armature. Hence, for a fixed level of current, the solenoids exert large forces when the valve is at their end of the stroke, but small forces when the valve is at the far end of the stroke. For example, when the valve is at the upper end of its stroke, the upward-acting solenoid can produce a large force with a relatively small current. However, when the valve is at the lower end of its stroke, a large upward force requires a very large current in the upward-acting solenoid.

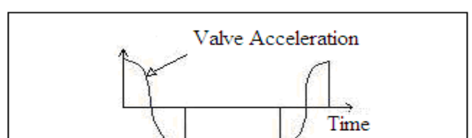
Free-flight dynamics for a normal-force actuated valve-spring system without friction, gravitational and gas forces: While considering the free-flight dynamics for a normal-force actuated valve-spring system without friction, and gravitational and gas forces, as shown in Fig. 4 [8] the kinematics profiles in Fig. 4 can be easily explained.



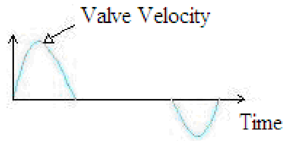
Combined Kinematic Profile for a normal force actuated valve spring system
Figure-4



Valve position profile for a normal force actuated valve spring system
Figure-4 A



Valve velocity profile for a normal force actuated valve spring system
Figure-4 B



Valve acceleration profile for a normal force actuated valve spring system
Ficure-4 C

1. Considering valve position profile: Suppose the valve is held closed by turning on the lower normal-force actuator. Ideally, if the valve were released, it would be accelerated by the springs past the equilibrium position of the system to its open position, where it would naturally stop. In reality, friction, and gravitational and gas forces prevent the valve from reaching the open position, and thus, near the open position, the second normal-force actuator is turned on, and the valve is pulled into its open position (Fig. 4A).

2. Considering valve velocity profile: As discussed earlier about the soft landing of valve which is one of the other desirable characteristics for VVT systems: the valves should reach either end of the stroke with very small velocity and acceleration (Fig. 4B).

3. Considering valve acceleration profile: In the idealized motion described above, the springs play a large role because they provide the large inertial power to accelerate the valve at the beginning of its stroke, and then to absorb the inertial power to decelerate the valve at the ends of its stroke. As was the case in conventional IC engine valves, this inertial power is regenerative because energy is stored in the springs instead of being dissipated. In addition, due to the electromagnet-actuators' nonuniform force-displacement characteristics, the current required to hold the valve open or closed (holding current) is small [8] (Fig. 4C).

Observation about free-flight valve-spring dynamics: The acceleration curve has discontinuities at both the end and beginning of the stroke. These discontinuities assume the instantaneous release of the valve at the beginning of the stroke and the instantaneous capture of the valve at the end of the stroke. These instantaneous actions require step changes in force and a true step force would create shock waves in the system and produce audible noise. To reduce this noise, it is possible to release the valves more slowly, but this lengthens transition time and increases the work which the capturing actuator must do.

Solution to the above problem: A possible solution to the control challenges in the normal force actuated valve-spring system is to attempt to use a bidirectional shear force actuator ([13], [19], [20]) to control the valve-spring system.

Need for a new technology: Automotive electrical systems today are moving towards higher power requirements. Due to the resulting Increase in electrical load, the automotive industry established a new 42V voltage standard that will eventually replace the current 14V system [21], [22]. Many of these innovations significantly increase fuel economy, and some involve the replacement of automotive mechanical systems with electrical systems [23].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 [7], [17]. Instead, if the engine valves are actuated as a variable function of crankshaft angle, significant improvements in fuel economy - up to 20% - can be achieved [6]. In addition, improvements in torque, output power and emissions are achieved.

As we are well known of the fact that in 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) [5]. VVT can be achieved using either mechanical or electromechanical actuation systems. With VVT alone, a 10% improvement in fuel economy can be achieved [6]. Furthermore, if the lift (how much each valve is opened) of the valves is controlled, another 10% 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 also so called camless engine. 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.

Requirement of an efficient valve: It must be gas tight without excessive friction, Opening and closing must be instantaneously, it must be accessible for cleaning, grinding, etc., and the gases must not be wire drawn

Different methods of opening and closing of valves in camless engines:

1. Valve springs: Valve springs, though used in all conventional valve systems, are the primary limiting factors on engine speeds, and generate many unpleasant effects, such as harmonics and valve float. Without them there is relatively little friction in the valve train. The current industry push to create a camless engine may be missing the point. The springs appear to be the problem, not the cam shafts.

2. Electro Mechanical: Electro magnets are used to open and close the valve and hold it in position once moved. This method of valve control is often found in camless engine designs. A proponent of this technology is Valeo, [24] which indicates that its design will be utilized in volume production in 2009.

3. Hydraulic: A piston driven by hydraulics is used to open the valve and compress a conventional valve spring. The valve is closed by the spring. The valve open and close is affected by valve mechanisms controlling the flow of hydraulic fluids to and from the hydraulic cylinder. This type of valve control has been advocated in the search for a camless engine. Sturman Industries [25], which incorporated its design into a large truck engine a number of years ago, is a proponent of this technology. (The truck did the hill climb at Pikes Peak). Various methods have been explored to utilize hydraulic mechanisms to move the engine valves. Some claim to be successful at low engine speeds, but few claim to achieve that goal meaningfully at the higher RPM requirements of passenger vehicles.

Hydraulic systems suffer from two inherent problems: Firstly, the faster a liquid is moved, the more it tends to act like a solid. A fast-acting hydraulic system to activate automotive valves at the speeds required in passenger vehicles could require immense pressures, with all the incumbent problems, including the additional energy requirements of the hydraulic pump. Even if higher engine speeds were achieved, valve movement would likely be abbreviated and not fully follow the desired or optimum lift schedule and secondly the temperatures can vary seasonally over a wide range. The hydraulic medium could change viscosity as the temperatures change, which could cause variances in the system's performance which may be difficult to control. Utilizing valve springs to assist the hydraulic system may also prevent the engine attaining higher speeds. In order to achieve gentle valve seating, hydraulic systems must be carefully controlled. This control may require the use of powerful computers and very precise sensors [25].

4. Stepper Motors: Stepper motors are used to open and close the valves. This methodology of valve control has previously not been successful in camless engine design due to the limited RPM range inherent in the design. Valves that open and close in fixed times, not tied to the engine speed, cannot optimize engines running at differing speeds and importantly severely restrict engine speed. This is because the degrees of rotation for the valve events increase as the engine speed increases to the point where they are no longer practical.

Powertrain [26] claim in their documentation that their device operates the valves at 8,000 RPM with a 7mm lift. . I don't dispute this claim obtained under laboratory conditions but anticipate that real world engines using their devices with 7 ms valve open and close times will have useful speeds limited to well under 6,000 RPM, perhaps even under 5,000 RPM (7 ms at 8,000 RPM is 336oof rotation which is unworkable in passenger cars). The engine may be able to run at higher RPM by limiting the lift and hence shortening the valve open close time but will most likely have a lower power output than is achieved at a lower RPM due to the lessening of breathing capability.

5. Pneumatic: Systems utilizing pneumatics to drive the engine valves would in all probability not be feasible because of their complexity and the very large amount of energy required compressing the air. Some F1 engines use a cylinder of pre-compressed gas to close the valves without valve springs while using conventional cam shafts to open the valve [27].

6. Desmodromic: The specific purpose of the desmodromic system is to force the valves to comply with the timing diagram as consistently as possible. In this way, any lost energy is negligible, the performance curves are more uniform and dependability is better. This form of valve control utilizes camshafts but not conventional valve springs. A long- time proponent of this technology is Ducati, which has successfully used this methodology in their motorcycles. This methodology removes the valve spring limitation on engine RPMs. However, other factors such as the use of rocker arms to open and close the valves may have a limiting effect on performance. A desmodromic system [28] does not normally provide for positive seating of the valves, as they are for the most part held closed by gas pressures in the cylinder. The exception could be the exhaust valve, which may be partially open in the "closed" position during the intake stroke.

7. Others: There is a number of mechanical valve operating systems based on traditional cam technology. Many rely on an offset gear to slow the cam as it opens the valve (and speed it up when it is not opening the valve), thereby prolonging the valve-opening duration. This together with cam phasing provides a limited form of variable duration. An example of this technology is the K series engine produced by Rover [29].

Problems with this methodology generally stem from the complexity and size of the units, the slow opening and closing of the valves, and the limited available variation in valve opening and closing times. Additionally, the valves may have to be lifted higher than their theoretical optimum height in order to achieve optimum gas flow. Some examples of this methodology are only provided for the inlet valves and others are limited to lower RPM ranges.

Then which is the reliable factor for controlling valve actuation ? The answer to the above question is –ECU. It was shown in [30] that the mass air flow rate through the throttle body and the intake manifold absolute pressure measurement in the camless engine can be used to estimate cylinder air charge. In this kind of engine in the pumping losses could be reduced significantly but we have to eliminate the manifold throttle valve which is the traditionally means for controlling the torque in SI engines. In case of camless engines the motion of inlet valve is controlled by an electronically controlled spring actuator. The actuator controls the inlet valve opening and closing of exhaust valve. During suction stroke, air enters the engine cylinder when the inlet valve is open. The mass of the air that enters the cylinder during breathing process is called cylinder air charge where as the energy loss is called pumping loss. Both of these factors depend upon the inlet valve opening and inlet valve closing timing. Therefore we have to design such a ECU which has to work upon 2 parameters

Parameter-1: Two inputs have to be provided and these two inputs are (i) Inlet valve opening timing and (ii) Outlet valve closing timing.

Parameter-2: (*i*) Cylinder air charge and (*ii*) Pumping losses.

Disadvantages of ECU: Its operation is based on graphical techniques, huge amount of stored data should be there, it is in the form of look-up tables and if some data is interpreted wrongly then it may not work properly.

Why engines do with ECU controlled valve timing work better ? Engines with ECU/computer controlled valve timing work better because of the following two main reasons:

1. *Broad range of near-optimum performance:* Engine operation varies in two significant dimensions: Variable RPM and Variable Fuel-Air Charge with each intake stroke (as controlled from the accelerator pedal.) Efficiency varies over this two-dimensional surface, peaking at one combination of RPM and fuel-air charge. Valve cams can be cut for optimization at one point on this surface, with efficiency dropping off anywhere else. Mechanical variable valve timing raises this efficiency surface at points removed from the optimized design point, broadening the range of near-optimum performance. Electromagnetic variable valve timing, under complete software control, can broaden the optimized range considerably more.

2. *Reduced pumping losses:* Fuel-air charge has previously been controlled by a throttle, which restricts the flow of air into the cylinder. Thus, as the piston passes bottom-dead-centre and the intake valve closes, the cylinder air pressure usually reaches only a small fraction of one atmosphere. All the air in the cylinder has been “dragged” across a flow resistance, dissipating energy. The only operating point with minimal “pumping loss” is full throttle, meaning that the cylinder is allowed to fill completely, up to intake manifold pressure. Engines are seldom operated at full throttle, so significant energy is lost to throttling. With computer-timed electromagnetic valves, there is no throttle [31]. The intake valve opens until the desired amount of air of fuel-air mixture is drawn in, and then closes to prevent further inflow. For reduced power, the intake valve closes early, then the piston proceeds down to bottom-dead-centre creating a partial vacuum, and then that vacuum pulls the piston partway back up until compression begins. The rebound of the piston, pulled by partial vacuum, contrasts with the more lossy response with throttled airflow The improvements arising from this increased range of near-optimum performance have been demonstrated by FEV in European road tests under standardized conditions comparable to the US EPA city/highway mileage tests [32]. Companies particularly (FEV and SIEMENS) have done the difficult engineering of valve actuators.

Problems faced by crank sensor and software’s: 360° of sensing, *i.e.* one square wave output, Cannot detect 720° without 2 crankshaft rotations,Camless engine software is time consuming, Engine Software manpower is expensive, specialized, and limited, Some new camless engine computers require water cooling to cool the processors, New camless engine computers are large compared to current computers, New camless engine computers require additional expensive processors and Less efficient in terms of input compared to camshaft engine with a camshaft sensor mechanically fixed.

Conclusion: The ECU should be designed in such a manner that it should have a feed forward controller, which will select the inlet valve lift and closing timing that will achieve the desired cylinder air charge. This cylinder air charge which will be purely based on drivers pedal push demand. DSP/ECU with hardware based CAM signals has to adjust the signals according to: Temperature of the engine, Temperature of the air and Manifold pressure and thus in return minimizing the pumping losses

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