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Design and Development of a System to Operate IC Engine Valves Electromechanically

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Abstract: Traditional internal combustion engines use a camshaft to control valve timing. Since the camshaft is rigidly linked to the crankshaft, engineers can optimize the camshaft only for one particular speed torque combination. All other engine operating points will suffer from a suboptimal compromise of torque output, fuel efficiency and emissions. The Designing of Internal Combustion engine system that operates on electromechanically is our approach to construct an electromechanical valve actuation system. Within the limits of the dynamic bandwidth of the system, it allows for fully user definable valve trajectories that can be adapted to any need of the combustion process.

1. INTRODUCTION

In an engine with an electromechanical valve actuation system, valve events are controlled independently of crankshaft rotation. In conventional Internal Combustion (IC) engines, the timing of intake and exhaust valves is controlled by the shape and phase angle of cams. Engineers need to choose the best compromise timing among fuel economy, emissions and torque, to design the shape of the cam. The optimization of cam shape is possible only at one engine speed. But I.C. engines in automobile application operate over speed and load ranges covering about an order of magnitude in each variable.

An electromechanical valve mechanism allows controlling the engine load without a separate throttle and thereby avoids the associated energy loss. It is also known that in a conventional engine the control of valve overlap, during which both the intake and exhaust valves are open, can affect the emissions, full load and idle performance. For example, to achieve high efficiency at high speed and high load, a large amount of overlap is desired, however, this will not allow the engine to idle smoothly at low speed and low load because the residual fraction is excessive. Therefore, engine designers are starting to consider electromechanical systems. The Valve Actuation which is nothing but a path to electromechanical engine system in our research is a very promising technology of its kind. It refers to the ability to control the duration (for how long the valve is kept open or closed), the phase (when the valve should be opened or closed), and the lift (how far does the valve move). Many presented systems have only provided duration and phase control and they are referred to as Variable Valve Timing systems.

Flexible intake and exhaust valve mechanisms can greatly improve fuel economy, emissions, and torque of the internal combustion engine. Fuel consumption may be reduced by 15% – 20%, torque output is enhanced in wide range of engine speed, and emissions may be decreased by the same ratio. This project aims at replacing the traditional cam engine using system which uses either an electromechanical system.

2. VARIABLE VALVE ACTUATION

Conventional engines are designed with fixed mechanically-actuated valves. The position of the crankshaft and the profile of the camshaft determine the valve events (the timing of the opening and closing of the intake and exhaust valves). Since conventional engines have valve motion that is mechanically dependent on the crankshaft position, the valve motion is constant for all operating conditions. The ideal scheduling of the valve events, however, differs greatly between different operating conditions. This represents a significant compromise in an engine's design.

In standard I.C. engines, the compression ratio (set by the engine's mechanical design) is also fixed for all engine conditions. The compression rate is thus limited by the engine condition with the lowest knock limit. Engine knock is caused by spontaneous combustion of fuel without a spark (auto-ignition). For spontaneous combustion to occur, the temperature and pressure must be sufficiently high. Therefore the limiting condition occurs at wide open throttle and engine speeds close to redline. Likewise, lower engine speeds and throttled conditions (the most common operating conditions when driving a vehicle) have much less tendency to knock and can withstand higher compression ratios (hence the potential for higher efficiency).

The most common operating conditions for Internal Combustion engines are low engine speeds and moderately throttled air flow. Unfortunately, the optimum conditions for the average IC engine are at WOT and low to moderate engine speeds. Throttling the intake air creates fluid friction and pumping losses. High engine speeds create greater mechanical friction thus reducing the efficiency. If the typical operating efficiency of the engine was improved, then the fuel economy would greatly increase. The most common use of Variable

Valve Actuation is load control. A normal engine uses throttling to control the load of the engine. When an engine is throttled, the flow separation created from a throttle body creates fluid losses and the volumetric efficiency decreases. A major goal of a Variable Valve Actuation engine is to control the amount of air inducted into the engine without a physical restriction in the flow field. The torque curve of a conventional engine has a very distinct peak that generally occurs in the middle of the engine speed range. The torque produced at low engine speeds is much less because the incoming mixture of fuel and air is at a comparatively low velocity. To increase the torque at low engine speeds, the intake valve should close right after the piston passes the bottom dead center between the intake and compression strokes. This will effectively generate a maximum compression ratio for low engine speeds. Increasing the compression ratio at low engine speeds essentially pushes the engine closer to a loaded condition.

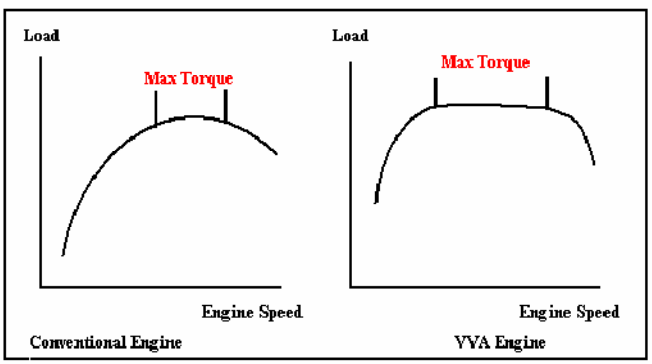

Figure 1. Torque Curve Comparison

Conversely at high speeds, the velocity of the intake mixture is large. Thus the optimum condition is where the intake valve stays open longer. The torque curve comparison between conventional and Variable Valve Actuation engines is shown in Figure 1. Another major use of Variable Valve Actuation is internal exhaust gas recirculation. The residual burn fraction is important for all engine conditions. At low engine speeds the percent of exhaust gas recirculation should be small, because combustion is already unstable. Moreover, adding combustion products to the intake charge only reduces the combustibility. At higher speeds exhaust gas recirculation can actually increase the efficiency and help produce more power. Exhaust gas recirculation is also important in limiting the emissions of an engine and reducing engine knock.

2.1.1 Cam Phasing

Another continuously variable VVA technology, cam phasing, focuses on cam timing instead of cam profiles. Cam phasing is a cam based technology that controls the phase of the camshaft in relation to the crankshaft. An engine with an intake cam phaser is shown in Figure 2. The typical cam phasing engine has a phasing range of about 40 to 60 degrees. The valve lift of an engine with cam phasing is presented in Figure 3. Although the effect of cam phasing may seem minor, it is actually one of the most robust technologies. One of the major goals of VVA is the control of the air flowing into the cylinders. The two previous technologies achieved this by controlling the valve lift. With cam phasing the amount of air ingested into the combustion chamber is controlled by either early intake valve opening (EIVO) or late intake valve opening (LIVO).

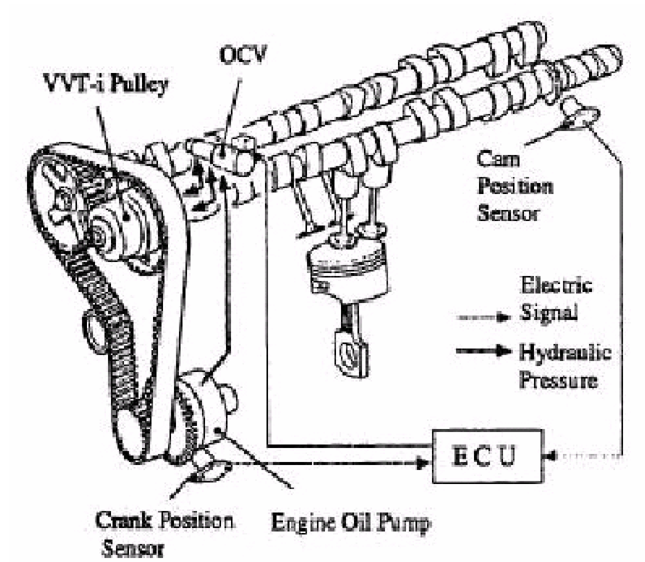

Figure 2 Cam Phasing Technology

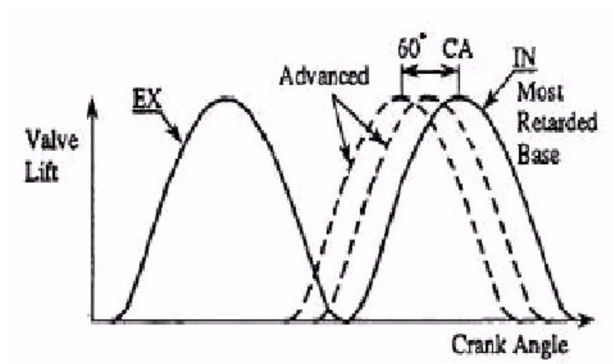

Figure 3 Valve Lift for an Engine with Cam Phasing

With early intake valve opening (EIVO) the intake valves are opened well before top dead center (TDC) of the crankshaft. The intake valves then close before the crankshaft reaches bottom dead center (BDC). The displaced volume is therefore much less than normal. Late intake valve closing (LIVC) does nearly the exact opposite. For LIVC the intake valves are opened at about TDC and then remain open past BDC. At high engine speeds the intake charge has a large momentum and will continue to fill the combustion chamber even after BDC. LIVC increases the volumetric efficiency at high speeds. Cam phasing of the exhaust cam can also allow for easier control of exhaust gas recirculation. The timing of the intake valve opening and closing can alter the effective compression ratio while also changing the expansion ratio.

3. VVT-I SYSTEM (VARIABLE VALVE TIMING – INTELLIGENT)

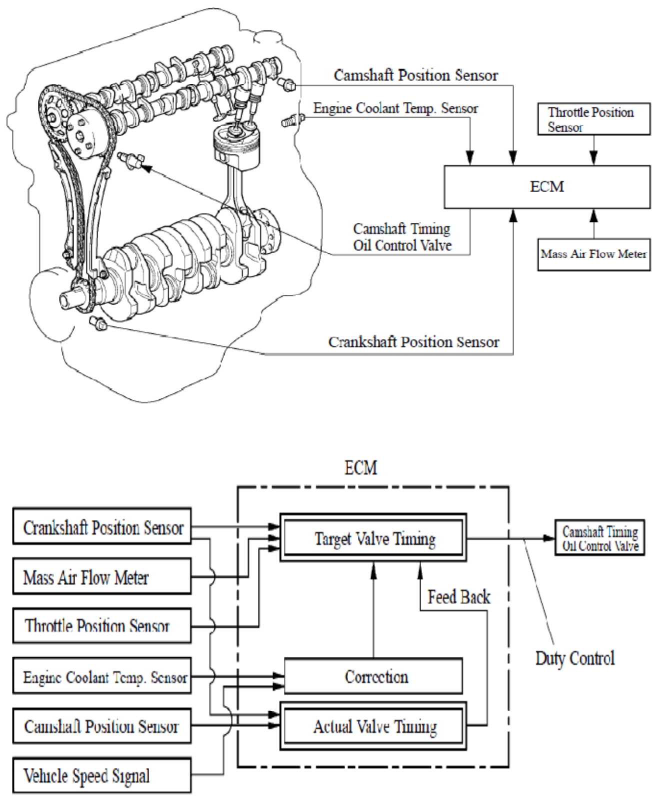

Figure 4 VVT-i System

This system controls the intake camshaft valve timing so as to obtain balance between the engine output, fuel consumption and emission control performance. The actual intake side valve timing is feed back by means of the camshaft position sensor for constant control to the target valve timing. It takes input speed from crankshaft with the help of position sensor and fed it to the camshaft through Electronic Control Unit.

4. ELECTROMECHANICAL SYSTEM

Figure 5 shows another electromechanical system, in which a Brushless DC motor is applied to drive the valve rather than solenoids. A number of different configurations exist for this design that all use springs to accelerate and decelerate the valve and a motor driven pivoting cam to provide timing. Note that the cam has a constant radius at either end of the valve motion. As a result, the motor can keep the valve at either end using zero torque.

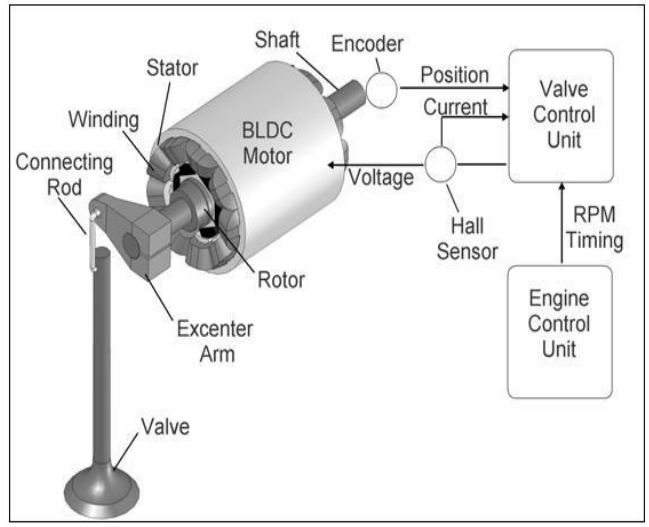

Figure 5 Electromechanical System

Since electromechanical systems provide better energy recovery potential, they will be used as benchmarks for the proposed Valve Actuation system. It combines advantages of the other electromechanical systems and avoids some of their inherent problems. It uses a Brushless DC motor to generate shear force to drive the valve. This leads to a much simpler linear control system than that for the Electromechanical Camless Valvetrain system. There are three main parts: the actuation part, the valve control unit and the engine control unit.

4.1 Design and Calculations

4.1.1 Engine Specification

Type	:	Four stroke
No. of cylinders	:	One
Bore	:	d mm
Stroke	:	l mm
Engine displacement	:	L cc
Compression ratio	:	R
Idling speed	:	N_i
Maximum net power	:	P_{max}
Maximum net torque	:	T_{max}

4.1.2 Cam Spring

There are two spring present at the valve stem of both inlet and exhaust valve. Both springs are in parallel connection.

Let,
K_1 : Stiffness of first spring
K_2 : Stiffness of second spring

Then,
Equivalent stiffness of both springs K_{eq}
$K_{eq} = K_1 + K_2$

Now Force require to overcome the spring force is,

Let.
Lift of cam be h mm
Spring Force be F_{spring}

It would be given as-
F_{spring} = (Equivalent stiffness of both springs K_{eq}) × (lift of cam h)
$F_{spring} = K_{eq} \times h$

4.1.3 Motor Design

Motor is essential part of the Electromechanical Valve System. So In order to design motor we need to find Power required to drive the cam shaft at idling and at various stages.

At idling,

$F_{Total1} = F_{spring}$ + Weight of Cam

But other than idling there would be a lot of force generated in combustion cylinder of an Internal Combustion engine. We have to consider that force as well in other conditions than Idling. We'll have to consider only mean pressure of cylinder It can be calculated as:-

$F_{Chamber} = P_{mean} \times A$

Where
P_{mean} = Mean effective Pressure inside cylinder
A = Surface Area of cylinder
$= \pi dl$

Then,

Total force would be
$F_{Total2} = F_{spring}$ + Weight of Cam + $F_{Chamber}$

Torque required to drive the cam shaft,
T = (Total Force acting on the camshaft) × (radius of cam shaft) × (FOS)

For Idling,
$T_1 = F_{Total1} \times R_{camshaft} \times f$

For other than idling,
$T_2 = F_{Total2} \times R_{camshaft} \times f$

Hence,

Power required to drive the camshaft,

$$P= \frac{2\pi NT}{60}$$

Again for Idling,

$$P= \frac{2\pi \text{NiT1}}{60}$$

Other than idling,

$$P= \frac{2\pi N\text{T2}}{60}$$

Maximum range of speed of motor is determined by the speed at which engine is running with maximum speed. Generally the reduction speed between the crankshaft and camshaft is half. So the speed of camshaft is (1/2) of crankshaft.

4.2 Why to use Brushless DC motor

Compared to brush DC motors and induction motors, BLDC motors have many advantages and few disadvantages. Brushless motors require less maintenance, so they have a longer life compared with brushed DC motors. BLDC motors produce more output power per frame size than brushed DC motors and induction motors. Due to superior thermal characteristic, the size of BLDC motor is reduced and Because BLDC has the windings on the stator, which is connected to the case, the heat dissipation is better. For these reasons the output power of BLDC is high. While in case of DC motor, the heat produced by the armature is dissipated in the air gap, thus increasing the temperature in the air gap and limiting specs on the output power.

Because the rotor is made of permanent magnets, the rotor inertia is less, compared with other types of motors. This improves acceleration and deceleration characteristics, shortening operating cycles. Their linear speed/torque characteristics produce predictable speed regulation. With brushless motors, brush inspection is eliminated, making them ideal for limited access areas and applications where servicing is difficult. BLDC motors operate much more quietly than brushed DC motors, reducing Electromagnetic Interference (EMI). Low-voltage models are ideal for battery operation, portable equipment or medical applications. The speed range of BLDC Motor is high as compared to the brush DC motor. It is due to the no mechanical limitation imposed by brushes in case of the BLDC Motor. While due to presence of the brush in DC motor, there is limitation on the speed range. Efficiency of BLDC motor is high as compared to the DC motor, because there is no voltage drop across the brush.

5. ACKNOWLEDGEMENT

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