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Design of Electromagnets for Camless Engines

Subhash Chander*, Kanwar Jabar Singh Gill**, Anil Kumar, Vipin Saini and Sarita*****

**Department of Mechanical Engineering, N.I.T. Jalandhar, (PB)*
***Department of Mechanical Engineering, Mahatma Jyoti Rao Phoole University (MJRPU), Jaipur, (RJ)*
****Department of Mechanical Engineering, College of Engineering amd Management, Kapurthala, (PB)*

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ABSTRACT : Electromagnets play a very vital role in camless engines. Electromagnets are fully responsible for conducting of smooth operation of camless engines. Electromagnet has to be coupled with a computer along with complex fast-acting control circuitry and devices which are mandatory to control the valves in real time. It should have a high traction force and, high armature acceleration. In order to have faster current, number of winding turns on the electromagnet coil should be reduced. Magnetic saturation and over heating of the coil has to be taken into account before giving power supply to the electromagnet. Lifters, Camshaft, Pushrods, Rockerarms, Heavy springs, Cam bore etc. all are reduced by simply employing electromagnets which in turn also reduces tooling and also Simplifies head design.

Keywords: Electromagnets,valve,armature, electromagnetic flux, voltage, traction force Designing parameters for an Electromagnet of a camless engine

I. INTRODUCTION

Now a day's automotive industry is severely suffering from decent market instability. Latest achievements in designing engine modifications using mechatronics; since past decade did not serve much comfort to automotive habitation. The development of cam in automobiles has been the important part of engine, as it opens and closes the valve at a required Stiming. The conventional valve train consists of a cam, a rocker arm and tappet assembly. For maximum efficiency of valve engine, overlapping of valve opening and closing proved necessary. Studies have shown that use of cam offers a compromise between maximum power and fuel economy.This lead to the concept of Camless engine where both maximum efficiency and power can be achieved simultaneously. The earlier attempts made during the design of Camless engine were based on the use of solenoids, which has its own limitations. It consumes considerable amount of energy and cannot directly operate valve velocity and displacement. Here efforts are being made towards overcoming above Problem

1. Actuation: The moving parts of the valve have to be accelerated with in a very short period of time during each valve opening. The weight of the moving parts must therefore be kept to a minimum. This reduces the force required to open and close the valve and improves control over the opening of the valve [1]. Constructed the valve stem out of thin tubing in order to reduce weight.

2. Electromagnetic Actuation: The main requirements of an electromagnet for sampling valve applications are, first, a high traction force and, second, high armature acceleration. The electromagnet traction force must be high in order to overcome the force of spring will be strong one, in order to ensure good scaling of the valve when closed. When electromagnet is energised, the acceleration of the armature is required to be high in many valve designs, so that the valve can be opened as rapidly as possible. It might be thought that an electromagnet with a high traction force would also have higher armature acceleration. In practice, this may not always be the case, because a larger traction force can be accompanied by a disproportionately heavier armature [2].

3. Increasing the electromagnet traction force: Fig. 1 shows a conventional electromagnet. The traction force is generated between the traction faces and the armature as shown in the Fig. 1 for a given traction face area; the traction force can be improved by increasing the magnetic flux. However, in practice, the maximum flux is limited by magnetic saturation of the electromagnetic material [2].therefore, if a greater traction force is required, usually then the traction face area of the electromagnet and armature must be increased, as demonstrated below. Let

f_a = armature acceleration

F_a = electromagnetic force on the armature

w_a = width of magnetic flux path (equal to thickness of the armature)

h_a = radius of the hole at centre of electromagnet and armature

ρ_a = density of armature material

k_e = constant

m_a = armature mass

From the discussion above, for given electromagnetic flux, the electromagnet traction force on the armature,

$F_a \propto$ total traction force area $\propto \pi\,(4h_a w_a + 6w_a^2)$ and $F_a = k_e\,\pi(4h_a w_a + 6w_a^2)$.

Therefore, the traction force can be increased by either increasing the width of the flux path, wa while keeping the hole radius, h_a, constant, or vice versa by increasing the hole radius, h_a, while keeping the width of the flux path, wa, constant.

The mass of the armature, m_a, is given by:

$$m_a = \rho_a \pi(6h_a w_a^2 + 9w_a^3)$$

Therefore, the armature acceleration, f_a, is given by:

$$f_a = F_a/m_a = 2k_e/3\rho_a w_a$$

Consider, again, ways in which the electromagnet force, F_a, can be increased:

1. Increasing the width of the flux path will increase the electromagnet force, but this will be at the expense of lower armature acceleration.

2. Increasing the radius of the central hole will increase electromagnet force, F_a, and this will not affect acceleration, f_a, is independent of hole radius, h_a.

3. It can therefore be seen that the latter is a more favourable option when traction force is required. However, in practice, this option may also result in a less compact design for the electromagnet. Often, practical electromagnets are designed with $h_a = 0$ and as their size increases the motion of their armature becomes slower.

4. *Increasing the Armature Acceleration:* In the above example, it is assumed that thickness of the armature will be equal to the width of the flux path, w_a, in order to provide an unrestricted flux path. In practice, as the electromagnet is operated transiently, the flux may not penetrate deeply, and the thickness of the armature could not be reduced without significant loss of performance [3]. This would reduce the mass of the armature and help improve its acceleration.

Another way of improving armature acceleration is to improve the build-up of the magnetic flux. In order to assist the rapid build-up of magnetic flux, eddy currents in the armature need to be minimized. Laminating the armature may be impractical, but the alternative but the technique suggested [4] of sitting the armature may be possible.

It has been established that reducing the number of winding turns on the electromagnet coil will provide a faster current due to reduced self-inductance [3]. The rate at which the magnetic field can be established is, however, still limited by the supply voltage. Voltage control has been used by [4] to provide rapid initial flux growth, and they report a corresponding improvement in device response. The voltage used however, is ultimately limited by the dielectric strength of the winding insulation. Since the duty cycle for the electromagnet coil is short, it is possible to operate the coil with currents considerably above the continuous rating, and thereby increasing the acceleration of armature. Finally, [2] describes the development of helically and conically shaped electromagnets which enable large transaction forces to be obtained with our significant compromise in armature acceleration. Pull in forces as high as 275 N have been achieved by such specialized heleniod and solenoid electromagnets [2, 5] and [6].

5. *Power supply to the electromagnet:* The amount of power that can be supplied to the electromagnet is limited by a number of consideration, including magnetic saturation and over heating of the coil. Because the electromagnet is switched on for a very small proportion of the engine cycle, it is possible to supply it with heavy current that is greater than its continuous rating. In some designs, this can increase the force provided by the electromagnet. However, if a circuit malfunction occurs and the power supply to the electromagnet stays continuously, then the electromagnet may be damaged due to over heating. Some means of avoiding this situation may be necessary, such as a timing circuit that switches power off should power to the electromagnet stays on for longer than a fraction of second. Alternatively, current to the electromagnet could be supplied by discharging a bank of capacitors through the coil. This has the inherent advantage of allowing current to flow for limited period only. Capacitor banks have been used by a number of investigators [7-9]. For example [1] used a trigger signal from a crankshaft sensor to operate a silicon-controlled rectifier discharging a number of capacitors through the electromagnet of the sampling valve. The charging voltage across the capacitor bank and the number of capacitors were adjustable so as to allow variation of the magnitude and duration of the current pulse.

6. *Control of Valve Electromagnet:* One of the ways to control the electromagnet valve working is shown in Fig.2. According to the figure, a shaft encoder is driven by engine crankshaft .This encoder provides two output signals. The first is a pulse once every engine cycle; *i.e.* once every two engine revolution (720 °CA) in the case of a four stroke engine. This once-per-cycle pulse could be arranged to occur, *e.g.* at bottom dead centre (start of the compression stroke). The second output signal from the shaft encoder is a pulse every degree crank angle of crankshaft rotation.

The first counter, labelled "valve on" is preloaded with the crank angle at which the electromagnet should be switched on. This crank angle can be preloaded using, e.g. ,thumbwheel switches (labelled "stored °CA for valve on" in the below given Fig. 2). The once-per-cycle bottom dead centre signal from the shaft encoder starts this "valve on" counter. Once started, this counter then counts the shaft encoder crank angle degrees and continuously compares the instantaneous counts with the pre-loaded value of "stored °CA for valve on". When the preloaded value is reached, a signal is sent to the on/off controller, which, in turn, switches the power supply to the electromagnet on. The second counter as shown in above given figure and labelled "valve off", is operated in precisely the same way as the first counter ,except that it is pre-loaded with the crank angle at which the electromagnet should be switched off. Both the counters are started simultaneously by the once-per cycle-pulse.

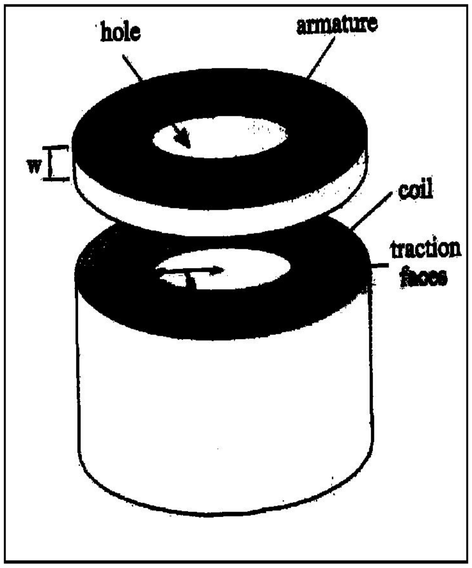

Fig. 1. General Structure of Electromagnet.

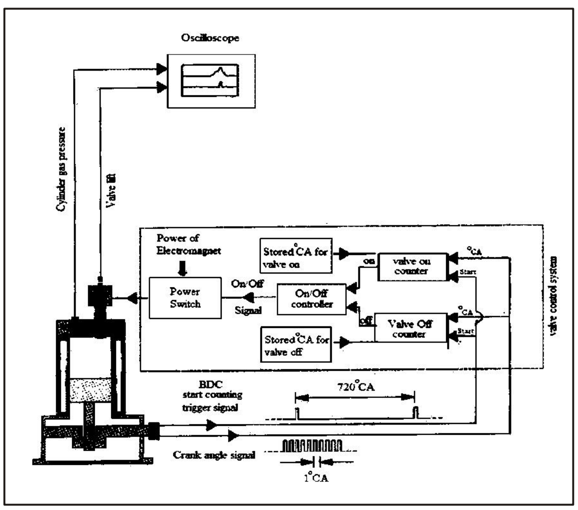

Fig. 2. Control System for Electromagnetic Valve.

It can thus be seen that the "valve on" counter control the timing (*i.e.*, the °CA) at which the valve electromagnet is .on the other hand the "valve off", counter controls the timing (*i.e.*, the °CA) at which the valve electromagnet is switched off and, thereby,the period for which current is supplied to the electromagnet. For example, if a greater number of °CA elapses before the "valve off", timer switches off the current to the valve electromagnet, then the valve will remain open for a longer period.

A period of several °CA elapses before the poppet valve opens. This is because a finite period of time is required for the electromagnetic flux to be established in the valve electromagnet coil. In addition, due to mechanical inertia, time is required before the electromagnet armature and the valve poppet connected to its starts to open. Therefore, it is necessary for the electromagnet current to be switched on ahead of the time (°CA) at which the poppet valve is actually required to physically start opening. The dead time or time (°CA) delay between the electromagnet current being switched on and the poppet valve starting to open depends on a number of variables (*e.g.*, engine cylinder gas pressure) and is difficult to predict. For this reason, it is necessary to have a sensing system which detects the timing (°CA) at which the poppet actually starts open and to display this timing to the valve operator.

Similar comments apply to the closing of the valve poppet. Once the current to the electromagnet is switched off by means of a signal from the "valve off" counter, a period of several °CA elapses before the poppet starts to actually close. Again, this is because a finite period of time is required for the electromagnetic flux to collapse in the electromagnet coil. In addition, due to mechanical inertia, time is required before the electromagnet armature at the poppet valve connected to it start to move. It is therefore necessary to switch off the electromagnet current ahead of the timing (°CA) at which the poppet valve is physically required to start closing. As this time delay is difficult to predict, it is necessary to have a system sensing the motion of movement of the poppet valve and display this to the operator.

If the two counters used are not able to reset themselves automatically, then some means of resetting the two counters once per engine cycle will be needed, perhaps through utilizing somehow the once-per-cycle bottom dead centre signal [10].

Converting a Camshaft Engine to a Camless Engine

In a pushrod engine, remove lifters, pushrods, rocker arms, springs and valves from the head. Leave ineffective camshaft in place for the distributor timing and function. Seal off oil passages in head, machine head and valves to fit new camless valve actuators. Install amplifiers, install new distributor and programmed DSP/ECU. If you have a 350 HP and 350 FT LBS TQ engine and then converted it to a camless engine, you may achieve up to 420 HP and 420 FT LBS TQ with 20% better gas mileage and 20% less emissions [11].

Camless Engine Cost Savings

Some of the major parts and technique used which are removed from an ordinary power house and converting it into an camless engine are as follows and these parts are responsible for cost saving: Lifters, Camshaft, Pushrods, Rockerarms, Heavy springs, Cam bore, Reduce tooling, Simplify head design, Increase overall productivity, Estimated savings per vehicle >$1000 [12], Clean air is the biggest cost of all.

Advantages/Benefits of Camless Engines

1. Reduced Emissions: Exhaust valve timing will control the retention of exhaust gas for controlled EGR, without introducing extra hardware for a regulated external EGR circuit.

2. Right stoichiometric ratio: Valve timing will interact with carburetion to give computer control of both the fuel/ air charge and the ratio mixture, without going to the expense of fuel injection.

3. Increased torque, durability, engine life, and allowing compensation for different types of fuel and varying altitudes: Due to infinitely variable valve timing more torque is made available through out the rev-range due to the valve timing changes enabling optimal volumetric efficiency. This increases engine performance and decreases fuel consumption, also decreasing harmful emissions, increasing durability and engine life, and allowing compensation for different types of fuel and varying altitudes.

4. Increased fuel economy: Siemens claims that even today, fuel savings of at least 10% can be obtained in the European test cycle by using a camless valvetrain. Further fuel consumption reductions could be obtained by combining camless valve technology with a high-pressure direct fuel injection system. (Siemens has also developed this type of system and it's expected to be part of the camless valve train engine when it does reach production readiness) [13].

5. Lower manufacturing cost: When this technology comes under mass production then it would have less manufacturing cost as compared to camshafts as there would be: No Lifters, No Camshaft, No more Cam bores, No Pushrods, No Rocker arms, No Heavy springs, No tooling of camshaft and Simplify head design.

6. Reduce packaging: In a pushrod engine, lifters, pushrods, rocker arms, springs and valves from the head are removed which reduces complicated package of the head.

7. Can be applied to any engine: Retrofit camshaft engine to a camless engine with some alternations.

8. Throttle body removed as well as associated pumping losses: Computer timing of valves will eliminate the carburettor and throttle plate, making way for a simplified no-moving-parts carburettor.

9. Optimised spark timing: The valve control microprocessor will simultaneously provide optimised spark timing.

10. No need to have an oxygen sensor: Valve controller has the potential for sensing combustion variables: specifically by sensing gas pressures and flow forces that affect the valve motion. This sensing is expected to lead to automated control of fuel mixture without the use of an oxygen sensor.

11. Control of adaptive spark advance: ECU would control adaptive spark advance and use valve timing to govern engine speed, sense and regulate intake air flow and fuel mixture.

12. Cylinder deactivation: An eight cylinder can become a six as needed! Is also possible, with the associated reduction in emissions [14].

13. Reduction in engine oil: The amount of engine oil required would also be dramatically reduced because no lubrication would be required for the traditional complex camshaft valve system.

14. Cold start wear: Cold start wear would also be minimal to the valve train hardware.

15. Power loss through valve train removed: There is also a general consensus that electromechanical valve actuation will increase overall valvetrain efficiency by eliminating the frictional losses of the camshaft mechanism, the weight of the mechanism and the cam mechanism's drain of power from the crankshaft.[13]

16. Designed to match valve-opening rates at the maximum engine RPM: The electromechanical valve actuators open the valve at this same rate regardless of engine operating conditions. Because of this improved speed, greater flexibility in programming valve events is possible, allowing for improved low-end torque, lower emissions and improved fuel economy. The massive opening period for the electromechanically driven valve can also be seen in the above figure.

17. Controlling the intake valve event: Controlling the intake valve event can also eliminate the need for throttled operation in petrol engines, thereby - the throttle butterfly becomes redundant! In the un-throttled camless engine, the intake valves' opening duration is used for cylinder airflow regulation, rather than a throttle or air-bypass valve. A simplification of the induction system results and a more compact engine design is thus possible. This leads to valve specific intake trumpets with less restriction to give the best breathing capabilities. Although, it needs to be said that there are reported problems with respect to idle control of a throttle less design, with stable un-throttled engine operation difficult to achieve during low load, and more precisely, during idle conditions.

18. Promotes scavenging: The intake valve may be opened and closed several times during the intake or exhaust sequence to promote scavenging and later to follow the piston to promote intake volumetric optimization, and intake and exhaust valves may be dithered to control engine throttling and braking.

19. Engine can operate in reverse or no need of reverse gear: Using camless valve actuators permits reprogramming to allow the engine to operate in reverse. This can be done by simply inverting one input wire pair. Reverse operation is advantageous in marine equipment having dual out drives or *T*-drives. This feature would also eliminate the need for reverse gear in the transmission since forward gears would be used to operate in either vehicle direction. This provides an opportunity for multiple reverse gears without the added hardware [14].

20. Removal of costly valve train components.

21. We can achieve Variable compression ratio.

22. Maintenance free operation.

23. Starter less operation.

Disadvantage/Drawbacks of this technology

1. Lack of input to the camless engine computer to determine valve timing: Now that the camshaft is gone, so are the camshaft sensor and its timed output which is used for fuel injection and ignition timing. This camshaft sensor displacement also affects the engine computers ability to time the cam less engine valves because it no longer measures the 720° interval. Therefore, the engine computer must measure the crank rotation twice, using one sensor, and then calculate all of the intervals for fuel injection, ignition and valve timing from software in real-time with one streaming square wave output [11]. This lack of input to the engine computer adds to the computers cost, complexity, production time and ultimately increase the chance of engine failure. Automotive manufacturers have noted that the valve actuators themselves are not what is holding the cam less engine back, it is the computer (software/hardware) in which is used to control such actuators that is holding back this technology

2. Limited valve control: When starting a camless engine, the valve timing input to the engine computer and the actual valve output during starting or cranking is very important for many reasons. Current camless engine systems use a system that employs a crankshaft position sensor to time the electronic engine valve function. In this system the engine computer must be zeroed to begin to control the electronic valve sequence. This means the engine must be cranked without valve instruction until the crankshaft and engine computer have been zeroed and then the ignition and fuel injection can be timed, and in this case the electronic valve function as well. When a camless engine is shut off, the sensors and computer power is gone, and the engine continues to rotate still, just momentarily. So when the engine is starting the computer does not know where the crankshaft has stopped because the sensors and computer lost power and count. This means the engine computer cannot determine the valve positions because it must locate the crankshaft position first. This set-up results in limited valve control if any, until the crankshaft has reached 0° to begin controlling the valves using the engine computer and the crankshaft position sensor. This lack of input could lead to internal engine damage or a high cranking load.

3. Huge amount of data storage: Very large amount of data has to be added to ECU for taking various decisions with in a fraction of second which is mandatory according to the drivers pedal push demand.

4. Deactivation of any valve could be serious: If any of the actuator fails it is not possible for that very valve to open or close which may create a very large problem.

5. Actuators have a non uniform force constant: The most popular method of controlling the valve-spring system is to use two solenoids: one to hold the valve open and one to hold the valve closed [15], [16] Fig. 3 shows a normal actuated valve-spring system [17]. Each electromagnet exerts a unidirectional normal force, and thus, the system employs two normal force actuators. 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, these actuators have a non uniform force constant. 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.

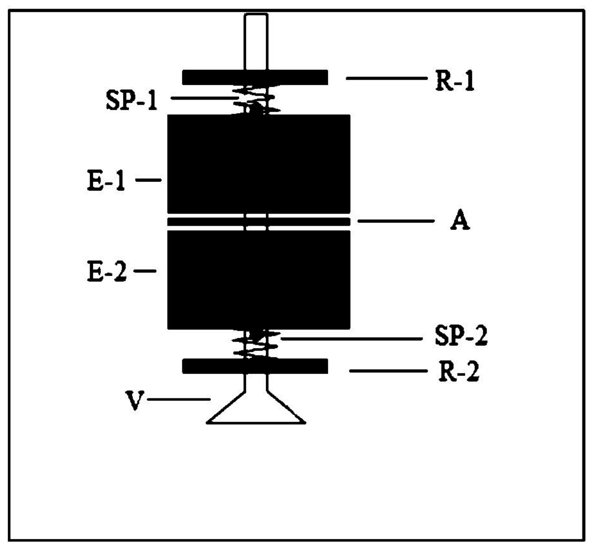

Fig. 3. Normal Force actuated valve spring system.

6. Noisy valves without servo control: Without servo control, electromagnetic engine valves can be noisy and wear out quickly.

7. Difficult to obtain deceleration of the valve: Deceleration of the valve once set in motion is difficult to accomplish, and inadequate slowing down of the valve can cause significant deterioration of the valve seat and other parts. Utilizing springs to effect valve deceleration limits the engine to lower speeds and may still not affect a gentle landing of the valve on its seat at all engine speeds

8. Careful balancing of the valve spring: Balancing with the valve utilized in this type of system may require very careful balancing with the valve movement in order to achieve gentle valve seating at differing engine speeds. As the springs deteriorate or the engine changes its RPM, the valve mechanism may become unbalanced and ultimately lead to failure

9. Requirement of unreliable motion sensors and sensor wiring: Servo control has to required expensive and unreliable motion sensors and sensor wiring

10. Requirement of powerful springs: Very powerful springs are needed for a high speed actuator and these power springs in return consume valuable engine real estate

11. Requirement of a higher capacity alternator: The electromagnets will draw a significant amount of electrical energy, which may require a higher capacity alternator, which will in turn reduce the potential fuel efficiency of the engine.

12. Requirement of complex fast-acting control circuitry and devices: A powerful computer coupled with complex fast-acting control circuitry and devices will likely be necessary to control the valves in real time.

II. RESULTS

Decrease in friction losses, Decrease in thermal losses, Decrease in mechanism of camshaft, higher output as it directly relates to torque and power of an engine, Better performance as we need not to fix our dial on economy zone norms, Better and clean environment for tomorrow, Easy to obey Euro. Norms, Better mileage, better pickup and easy to rock up a hill.

III. CONCLUSION

However, the future is not necessarily as rosy as the above states. There are many problems to be overcome with the electronically controlled valves. The problems lie not only in the software required but also the mechanisms of the actuators. Coil transient response times and saturation effects at high rpm are just some of the issues.

Stand assured though, that the answer to these problems is only a matter of 'when' and not if'.

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