Analysis and Synthesis of Discrete-Time Repetitive Controllers of Dynamic Systems, Measurement and Control Energy Saving Camless Engines

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Abstract

This paper presents the design of Camless Internal Combustion (IC) Engine using the Magnetic platter Disk Sensor instead of conventional mechanism for operating valves. In this work an attempt has been made to integrate the concepts of mechanical and electronics for designing economical, low emission, high performance Camless engine. Objective of this work is to make use of Disk Sensor for developing Camless IC Engine. The paper describes design, implementation and results as follows.

1. 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 timing. 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.

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2. Objective

To control electronically timed valves in a camless engine. An electromagnetic actuator found in a camless engine makes use of 2 signals to control the opening and closing movements of the engine valve. Therefore in a 16 valve engine you can expect to have 32 separately timed signals to operate the valves. The magnetic platter Disk Sensor would easily make available the 32 individual tracks which are needed to supply the signals to the valves. These 32 signals would come from 32 concentric circles of which are found on the magnetic platter disk. For each track on the platter we will have a matching magnetic read head. 32 tracks = 32 read heads. The fixed reading heads would be mounted over the tracks. As the magnetic platter disk would rotate in sync with the crankshaft, the 32 output signals, in different timing degrees, would be sent to the engine computer and then the valve. The magnetic disk platter has to be timed 2:1 to the crankshaft, just like a camshaft.

3. Literature Review

Originally, camless engines were developed for use as a design aide to automotive engine manufacturers. The use of a camless engine allowed the engineer to experiment with valve timing as a means of designing cam profiles. These early units were not limited by dimensional or power consumption restraints. Instead, they were solely developed for laboratory use as a design tool.

Aside from laboratory use, history shows that the idea of a camless internal combustion engine had its origins as early as 1899, when designs of variable valve timing surfaced [1]. It was suggested that independent control of valve actuation could result in increased engine power. More recently, however, the focus of increased power has broadened to include energy savings, pollution reduction, and reliability.

To provide the benefits listed above, researchers throughout the previous decade have been proposing, prototyping, and testing new versions of valve actuation for the internal combustion engine. Their designs have taken on a variety of forms, from electro-pneumatic to electro-hydraulic. These designs are based on electric solenoids opening and closing either pneumatic or hydraulic valves. The controlled fluid then actuates the engine valves.

Much of the remaining documentation deals with either the control of the solenoids or the computer modeling of such control systems. The research on the control of the solenoids is crucial since their precision and response is a limiting factor to the development of earlier camless valve actuators.

A comprehensive project using solenoid control of pneumatic actuators was completed in 1991 [1]. This research included the development of the actuators, a 16 bit microprocessor for control, and comparative testing between a standard Ford 1.9 liters, spark ignition, port fuel injected four cylinder engine and the same engine modified for camless actuation. Testing compared the unmodified engine to that of the same engine, altered to include eight pneumatic actuators in place of the standard camshaft.

The actuators used during the research required an off-engine power source because an engine mounted compressor was not feasible. The researchers found that for engine operation at 1500 rpm, the eight actuators used a total of 2.5 kW of power. This compares very high to the 140 watts of power consumed by comparable production engines. As Gould et al. states, their work cannot be considered feasible for implementation due to the high power requirements of the actuator.

For their project, pneumatic actuators were chosen after running comparison tests among different methods. Pressurized air was chosen due to its low mass, allowing fast response and stability over a broad temperature range. The researchers found that hydraulic systems had sluggish response, especially at low temperatures.

The pressurized air was controlled by electromagnetic valves. All flow path distances were minimized to increase the response time of the actuator by reducing the volume of air required for actuation. The pressurized air opened the engine valves based on the timed electrical signal input to the “electromagnetic latch.” Residual air was compressed during valve seating and provided a means of slowing the valve for a soft seat.

The researchers concluded that the test engine produced approximately 11% greater torque at low engine speeds (below 2000 rpm) compared to a conventional engine. Furthermore, the camless engine was capable of reducing emission gasses, specifically “brake specific nitrous oxide emissions” (bsNOx), but only by degrading the combustion process [1]. In 1996 the next generation of camless engine was completed at the Ford Research Laboratory by, principally, Michael Schechter and Michael Levin. Ford’s work has taken a detailed look at the plethora of parameters associated with consistent, reliable engine operation.

Beyond the basics, Schechter and Levin introduce a new concept of the hydraulic pendulum. It is stated that the use of a hydraulic pendulum decreases the system’s energy consumption by converting the kinetic energy of a closing valve into potential energy stored in the pressurized fluid. This reduces the energy required for pumping the hydraulic fluid. Through this conversion of energy, the authors predict that a 16-valve, 2.0 L engine will consume about 125- W to operate at light loads. The hydraulic pendulum also allows for the solenoid-based-system to slow valve velocity. This results in soft seating the valve and is a favorable attribute of the new system. Another benefit is the ability to vary the opening and closing velocity of the valve. This allows for increased variation to engine valve parameters. A schematic of the hydraulic pendulum is shown in Fig: 1. High and low pressure hydraulic reservoirs are connected to the engine valve’s actuating piston. The control of this fluid is accomplished by means of two solenoids and two check valves. High pressure fluid is always in contact with the lower side of the piston, and either high or low pressure fluid is in contact with the upper side of the piston. The difference in pressure contact area is utilized in conjunction with the hydraulic pressure to vary the actuating forces.

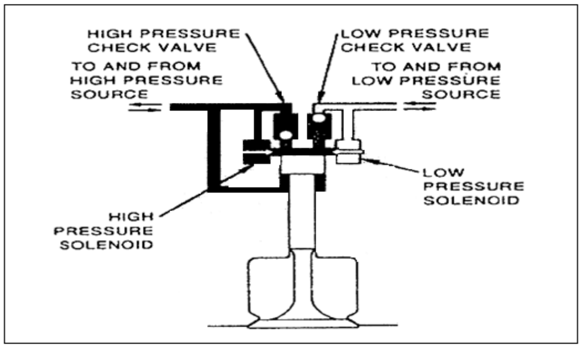

Fig: 1. Hydraulic Pendulum Schematic [2]

The authors provide a detailed description of the valve actuation cycle. This is summarized as follows. To open the engine valve, the high pressure solenoid opens to allow high pressure hydraulic fluid into the upper chamber. Due to the difference in pressure contact area, the valve opens. Next, the high pressure solenoid closes, but the valve's momentum continues to open the engine further. This causes a reduction of pressure in the upper chamber and allows the low pressure check valve to open. The engine valve decelerates as it pumps the high pressure fluid from the lower cavity back to the high pressure reservoir. This process both slows the valve and recovers some energy by converting the kinetic energy of the engine valve into potential energy in the high pressure fluid. Once the upper cavity pressure equalizes with the low pressure reservoir, the check valve closes and the upper cavity fluid is static. This allows the engine valve to be held open.

Closing the valve is initiated by the opening of the low pressure solenoid valve. The engine valve accelerates toward its closed position based on the force differential between the high pressure lower cavity and the low pressure upper cavity. The upper cavity fluid is pumped back toward the low pressure reservoir. Energy is again recovered and the engine valve is soft-seated through a similar deceleration process. By closing the low pressure solenoid valve, the upward momentum of the engine valve pressurizes the upper cavity fluid. This increase in pressure opens the high pressure check valve and allows the upper cavity fluid to be pumped back to the high pressure reservoir. Again, energy is converted from kinetic to potential and the valve is decelerated.

The best timing of this process would allow for the kinetic energy of the engine valve to be exhausted exactly when it closes. However, the researchers provide an alternative to such precision. Instead, they suggest stopping the engine valve just prior to contact with the seat, and then briefly opening the high pressure solenoid to complete the cycle [2].

Through the use of a hydraulic pendulum, a complete four cylinder ICE was produced and found some success. However, the system is complicated and requires multiple components. The use of a hydraulic pendulum requires two solenoids and two check valves per engine valve and both a high pressure and low pressure hydraulic fluid supply. (Schechter et al. state that two solenoids can run a pair of valves as-long-as the pair are synchronized. However, this detracts from the concept of independent valve control.)

The camless engine developed by Ford and described above was then enhanced at the University of Illinois at Urbana-Champaign. The focus of the project was to advance the hydraulic-pendulum-based CLE actuator by developing an adaptive feedback control. Their research is focused on the electronics and algorithms of data acquisition and control. The complete system was limited to operating at 3000 rpm. Valve lift greater than 5 mm could not be consistently controlled [3].

The authors raise concerns of component variation and its effect on the proper control of the engine valves. These issues rise mainly from the tolerances associated with the production of automotive components. Furthermore, the authors investigated the system changes due to fluctuations in hydraulic fluid temperature [3].Beyond the projects discussed within; little technical information exists on the development of the camless engine. More recent projects, including those at Siemens Automotive – Europe and International Truck and Engine Corporation represent the next phase of external CLE research.

In June, 2000, Sturman Engine Systems and International Truck and Engine Corporation completed their proprietary CLE project by being the first CLE based truck to reach the summit of Pikes Peak [4]. The International engine with Sturman hydraulic valves is a diesel system. One of the difference between diesel truck and gasoline passenger car demands is operating speed, and even experts familiar with the project have raised concerns about the electrohydraulic system capabilities at the higher speeds of passenger cars [5].Although the system is proprietary, one available detail is the hydraulic fluid used to actuate the engine valves is controlled by a spool sandwiched between two electrical coils [5].

Concurrent to the International Truck and Engine and Sturman Engine Systems development, Siemens Automotive has been advancing their version of the CLE. Siemens claims their Electromechanical Valve Train (EVT) is nearing production capabilities [6].Again, the system is proprietary, but some details are available. The Siemens' CLE is operating on the anticipated 42 volt bus and comes from an electrical distributor and crankshaft-mounted starter-generator. Special algorithms provide the current signal to the engine actuators and are capable of controlling valve velocity and soft-seating. Their actuator is based on a spring/mass system. Early results show a fuel savings of 10 percent. Siemens is currently working on the next phase, which will focus on sensor less actuator control [6].

The one common factor of all known CLE work is that none are using Magnetic platter Disk Sensor to control the engine valve actuation. It is this difference that makes this work a unique and may prove to be the necessary element to provide the next level of engine sophistication.

4. Methodology

The magnetic disk platters media, or material being read, determines the strength and type of signal. The disk platter can produce analog and digital signals or both at the same time. Hundreds of individual tracks would be available for timed information storage on the platter disk, thus allowing for fuel injection and spark ignition timing to be achieved as well. Spark ignition and fuel injection would simply be more dedicated tracks on the disk platter, which leaves a relatively small footprint. If you have a 32 valve engine you may have 64 signals plus 8 fuel injection and 8 spark ignition signals, totaling 80 independent signals. The disk platter would easily support this requirement. Both intake valves in one cylinder do not have to open at the same time or the same amount when using the Disk Sensor, thus showing great flexibility of the Disk Sensor.

As the Disk Sensor would be driven by the crankshaft via timing belt, the media on the disk is read in real-time by the magnetic heads which are fixed over the tracks. Like a personal computer's hard drive where you find *mobile* read/write heads, there is also a *mobile* read/write head which is used in the magnetic platter Disk Sensor. This *mobile* read/write head will modify the track signal strength accounting for wear and other corrections while the engine is running. This allows the *fixed* read heads to read the modified signals uninterrupted.

5. Requirement of disc sensor

- Disk Sensor has to retain the important 2 to 1 timing ratio that the camshaft utilizes. This ratio is important because of the 4 stroke cycle and the detection and distinction of 720 degrees of rotation from the crankshaft to time the engine valves.
- The Disk Sensor has to supply the computer with hardware based "cam" signals. The computer will then adjust the signal according to the engine temp, air temp, manifold pressures etc.

6. Current problem facing by Camless Engines

Problem: 1. Lack of input to the camless engine computer to determine valve timing. Now that the camshaft is gone, so is the camshaft sensor and its timed output which is used for fuel injection and ignition timing. This camshaft sensor displacement also effects the engine computers ability to time the camless engine valves because it no longer measures the 720 0 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. This lack of input to the engine computer will increase the cost of computers, complexity, and 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 camless engine back, it is the computer (software/hardware) in which is used to control such actuators that is holding back this technology.

Solution: 1. The solution to the above problem is "Disk Sensor". The Disk Sensor will output all of the fuel injection, ignition and valve profiles Precisely, Repeatedly, Reliably and Simply all in Real Time. The Disk Sensor would be physically connected via a belt and timed to the crank 2:1 just like a camshaft is reliably timed to the crankshaft. The Disk Sensor is the hardware that is needed to support the software. This will eliminate the valve timing challenges that are presented to a camless engine computer using only one crankshaft position sensor. The Disk sensor will significantly help the engine computer start a camless engine.

Problem: 2. 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 setup results in limited valve control if any, until the crankshaft has reached 00to 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.

Solution: 2. When the ignition will be turned on, then the Disk Sensor will immediately responds to the information on the magnetic platter and the electronic engine valves move into position before the engine starts cranking. This pre-start camless engine valve placement ensures that the engine can crank safely and efficiently. More specifically, in the Disk Sensor, one track is specifically dedicated to the 7200 increment timing interval for the computer timing function and other systems. One such system using the 720 increment track will also be placed in the in the starting system. The 7200 increments (00 to 7200) on a 3600wheel, is used for immediate valve placement. An optical or magnetic reading device will be used in the timing track. In the magnetic platter Disk Sensor, the magnetic heads read the magnetic media signals which are strength in mill volts from 00 to the 7200th increment on the 3600 track. As the tracks increment increases from 00 to 7200, so does the voltage signal produced from the track. If the magnetic head sensor detects 418 mv from the platters track while the engine is off, key on, this indicates a particular position for the crankshaft and valve position and that voltage (418mv for ex.) is referenced to a table to identify the engine position in degrees, say 3200, of which the valves will have a specific placement and at such point will fall into position.

As soon as the engine has turned the slightest by the starters' activation or by a starter less system which closes some selected valves and injects those cylinders with fuel and by igniting such cylinders, all of which can be programmed by such technique provided above, the Disk Sensor starts to produce regular valve, fuel, spark timing, etc. Signals from the large quantity of individual tracks of which are dedicated to such specific outputs.

The minimum or base reference voltage has to be used to position the valves to open a specific amount during startup thus allowing startup. Additionally the voltage applied to the valves during starting will be similar to the base voltage during idle. The computer will also adjusts the valves voltage and movement according to temperature and other sensors input, but these other sensors will have much less effect on the valve opening/closing when compared to the effective voltage increase/decrease from the throttle position sensor input.

The engine computer simply waits for the input signals which are produced by the disk platter in real time, timed directly to the crankshaft. Without the Disk Sensor, the engine computer has only one input of which must be decoded into 7200 from 2 crankshaft revolutions and potentially control over 80 independent signals with not even a camshaft sensor. (64 signals for 32 valve engine (2 signals per actuator) + 8 signals for fuel injection + 8 signals for spark ignition = 80 signals).

7. Advantage

1. By timing the Disk Sensors pulley to the crank (2:1); timing issues are eliminated.
2. The Disk Sensor will offer discrete electronic fuel injection, spark ignition and valve timing signals.
3. The Disk Sensor is a cost effective.
4. Simple in design.
5. Reliable system.
6. Save design time, money, increase quality.
7. Restore important 720 degree timing interval
8. Supply the engine computer with separate predetermined signals at specific timing intervals for function of the valves, fuel injection, and spark timing
9. Reduced emissions
10. Real time data
11. Increase horsepower
12. Increased torque
13. Increased fuel economy
14. Reduce packaging
15. Lower manufacturing cost
16. Maintenance free
17. Can be applied to any engine
18. Starter less operation
19. Retrofit camshaft engine to a camless engine
20. Power loss through valve train removed
21. Removal of costly valve train components
22. Cylinder deactivation
23. Variable compression ratio
24. Throttle body removed as well as associated pumping losses

8. Camless Engine Cost Savings

Lifters, Camshaft, Cam bore, Pushrods ,Rocker arms, Heavy springs ,Reduce tooling ,Simplify head design, Increase overall productivity as the above given components are not available.

9. Advantages of Disc Sensor Software

1. With Disk Sensor software, one can create, test and tune any desired valve profile for any engine

fitted with the Disk Sensor and camless engine valve actuators.
2. The Disk Sensor is programmable Hardware
3. One Disk Sensor software package could design thousands of disks using a personal computer while the Disk Sensor writes the new signals internally. This software would be available to qualified performance shops.
4. The Disk Sensor allows you to change valve profiles, fuel injection timing and spark ignition using reading/writing magnetic heads.
5. It is possible to write the new profiles onto separate tracks while the engine is running and then switch to those tracks, but this would not allow the user to test the valves performance while the engine is off.

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