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A review of new technologies in valve systems of internal combustion engines and their effects

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Abstract. Efficient use of energy is becoming increasingly crucial due to global warming and depleting fossil fuel sources. Automotive manufacturers aim for fuel economy, reduction of exhaust emissions, durability, volume and weight reduction, and power and torque increase in internal combustion engines. One of the most important developments in this field is the new technologies in classic valve systems. There are still ongoing studies in this field as the gas exchange processes affects all engine parameters. In this review; the principles of new technologies used on classic valve systems and their effects on engines have been investigated. The research has shown; new mechanism technologies used on valve systems have positive effects on engine performance, power, torque and fuel consumption.

1. Introduction

Efficiency in engines has become a primary objective in recent years due to the rapid development of automotive industry, depleting oil derivative fuels, increasing exhaust gas emissions and as a result of cost analysis and supply and demand ratios. The valves in internal combustion engines are opened and closed by the camshaft. The biggest problem in standard use of the camshaft is that the valve opening duration and lift are fixed. In these type of engines, the camshaft delivers an appropriate volumetric efficiency in low speeds, but it's negatively affected in high speeds. As speed increases in internal combustion engines, the gas intake volume and speed continues to change in relation to the piston speeds. Thus, the valve timing should also be changeable.

2. Innovations in valve technology

Many studies have been made in the automotive industry for developing valve systems that will increase the volumetric efficiency, and thus improve the internal combustion engines. There is still ongoing research in this field. In conventional engines, the intake valves within the cylinders let the gases into the cylinder, and the exhaust valves dispose the burnt gases out of the cylinder. Larger valves increase the volumetric efficiency. As the valves get larger, the intake and exhaust of the gases get easier. However, bigger valves also mean that the spark plug gets farther away from the combustion chamber, which decreases efficiency. For better volumetric efficiency, it makes more sense to increase the number of valves, rather than the size. Initially, the engine manufacturers have increased the intake and exhaust numbers per cylinder to create multi-valve systems. Multi-valve technology has increased the gas efficiency within the cylinder [1]. In internal combustion engines, variable valve technologies are now being used to ensure the power and torque increase at wider speed ranges. In recent years, the gas intake can be increased even more with variable valve timing coupled with variable valve lift controls. Thanks to all these improvements, internal combustion engines have better fuel economy, higher power and torque [1].

In the automotive industry, the studies on valve technologies show that, engines with high efficiency, more flexible valve timing and valve lift are now being produced. With today's technology, it’s possible to increase fuel economy and reduce exhaust emissions in multi-cylinder engines, by deactivating some cylinders when the additional power is not needed. In this context, there is still on-going research on the valve mechanisms in electromechanical, electrohydraulic, electro-pneumatic and electric motor driven systems [1].

In electromechanical valve systems, there is an electromagnet for each valve and an electronic control unit that controls the valve system. In these systems, technologies such as variable valve timing, variable valve lift and the disabling of some cylinders can be used more easily [2]. In engines designed with this technology, the problems of noise and valves hitting against the covers have also been somewhat eliminated [3-5]. Additionally, increased fuel economy and reduced exhaust gas emissions have been observed.

When the electrohydraulic valve systems are examined, the stem of the valves works in connection with a hydraulic cylinder. The system works with filling and discharging a fluid into the hydraulic cylinder in the valve stem. Opening and closing of valves is managed by directional control valves of the fluid. The required pressure difference for the system can be provided either by the lubrication system of the engine or by an external electric motor [6].

Electro-pneumatic valve systems show fundamental similarities with the electrohydraulic systems. In this system, air is used as a fluid. It is preferred especially in valve systems where greater power is needed. This system operates efficiently at normal speeds but suffers when operating at low speeds [7]. Additionally, variable valve lift control and contact problems sometimes occur in the engines where electro-pneumatic valve systems are used.

Recently, some studies have been conducted on valve systems driven by electric motors. This system is also based on variable valve timing and variable valve lift. The engines with electric motor driven valve systems offer lower power consumption [8].

3. Variable valve mechanisms

Two of the biggest parameters affecting the engine efficiency the most are valve timing and lift. In modern engines, the intake valves are opened before the piston reaches the top dead centre (TDC) and closed after it passes the bottom dead centre (BDC) to increase volumetric efficiency. Similarly, exhaust valves are opened before the piston reaches BDC and closed after it passes TDC. In this way, maximum performance and efficiency can be achieved. In the past, the camshafts were designed with a set working range. In these type of engines, the biggest setback of using a standard camshaft is not having the ability to change the valve timings and lift. Even though these engines provide a viable performance in low speeds, the power drops in high speeds. Full efficiency can only be achieved within a small revolutions range in the engines in which a standard camshaft is used. Conversely, the valve lift in high speeds causes a drop in power in low speeds. High angle camshaft offer a high performance in high speeds, but causes rattling and noise when operating in low speeds. In order to avoid all these problems, the automotive industry has developed engines with variable valve mechanisms with high efficiency, which will ensure perfect performance in varied working conditions.

3.1. Audi valvelift system

In this system, the valves are controlled by the low speed cam or the high speed cam on the camshaft, depending on the engine speed. When the engine is running at low speeds, the low profile cam mechanism is activated for a narrower lift. In increased engine speeds, the high cam is activated to increase the lift. The activation of the low and high cam profiles on the camshaft is made by two electromagnetic mechanisms. In the Figure 1, the activation of low and high cams is indicated by red and green arrows. This increases the efficiency in relation to the amount of air entering the engine cylinder [9]. Friction is also reduced because there are fewer components in variable valve systems. About an additional 7% fuel economy can be expected in the engines where this system is used [10].

Figure 1. Audi Valvelift System [11].

3.2. BMW Valvetronic System

With this technology, there is no need for a throttle valve because it has a different type of software and control system compared to other variable valve mechanisms. It boasts a fully equipped intake valve that adjusts the amount of air required for the engine, and eliminates pumping loss. Developed by BMW, this system consists of an additional camshaft, which allows the opening and closing of the valves, a monitoring sensor, a spiral gear system and an electric motor. The timing of the cam shaft and the opening duration of the valves are regulated by the spiral gear system, which is driven by the stepper motor. One of the most important features that distinguish this system from others is that the cooling water temperature at the cylinder top surface is much lower [12]. Due to the lower temperature of the cooling water, a smaller volume circulation is used and less power is required from the engine. Motors using this system operate easily and quietly in cold weather conditions. In addition, fuel consumption and harmful exhaust emissions are lower compared to other engines [13].

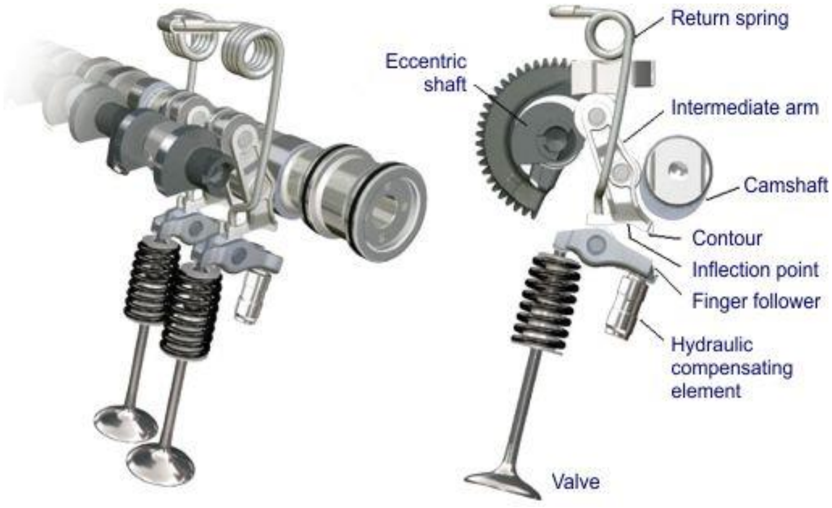

Figure 2. Valvetronic system as developed by BMW [14].

3.3. Porsche VarioCam System

Similar to other variable valve timing mechanisms, this system changes the angle of the camshaft according to the position of the crankshaft. The difference is, this system not only controls the intake valves, but also the exhaust valves. When the system is activated, the intake valves are closed earlier because the lapping duration of intake and exhaust valves are longer. As a result, more torque is obtained from the engine [15]. As in other systems, the camshaft is composed of low and high cam, which controls the valves according to the speed of the engine. The drive system, which changes the angular position of the camshaft, operates with hydraulic oil.

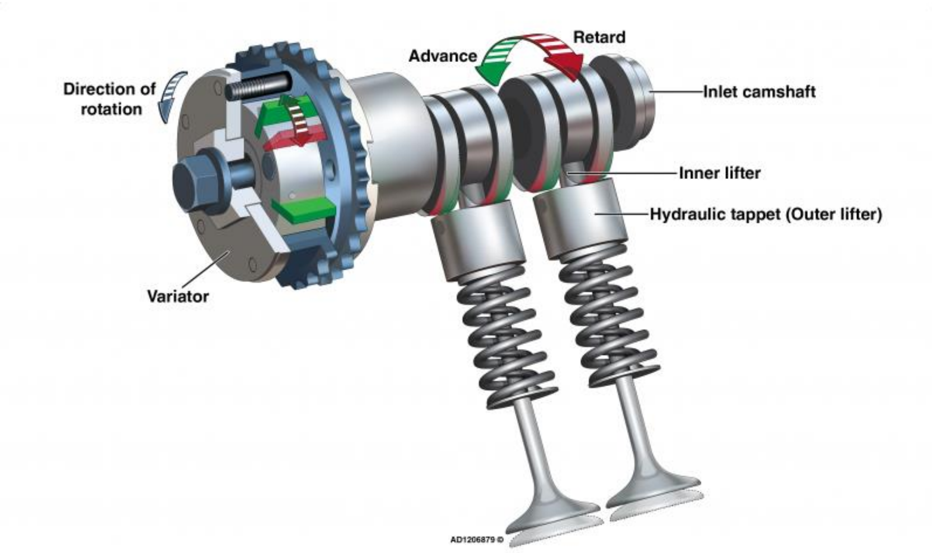

Figure 3. Porsche's VarioCam System [16].

3.4. Toyota VVTL-I system

Developed by Toyota, this technology aims for creating more momentum in low speeds and more power in high speeds by controlling the timing and lift of the valves [17]. Like other variable valve mechanisms, there are high and low cam profiles on the camshaft. The rocker has a two-piece design for making the switch between these cam profiles easier. The transition between the cam profiles on the camshaft is made by hydraulic oil pressure working the locking pin. The low cam is active in low speeds. When the engine speed reaches 6000 rpm, the oil pressure is increased and the high cam profile gets activated, resulting in higher power [17].

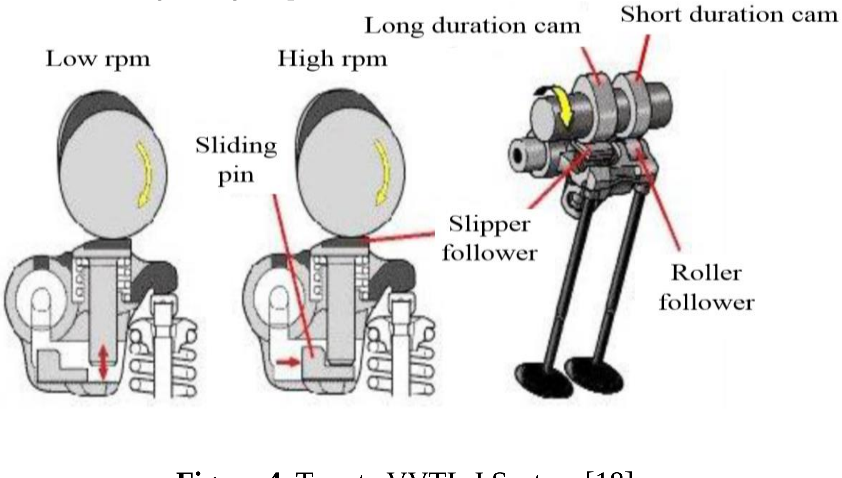

Figure 4. Toyota VVTL-I System [18].

3.5. Fiat MultiAir System

The MultiAir system offers better combustion control and a faster response to torque requests. This means concretes advantages in terms of:

- Lower fuel consumption
- CO_2 emission reduction
- Power and torque increase
- Higher driving responsiveness
- Easier start-up.

The MultiAir system is managed by injection/ignition control unit which controls the operation of the intake valves. In this way the fluid inside the engine can be changed without resorting to the traditional expansion on the throttle valve [19].

Figure 5. MultiAir System [19].

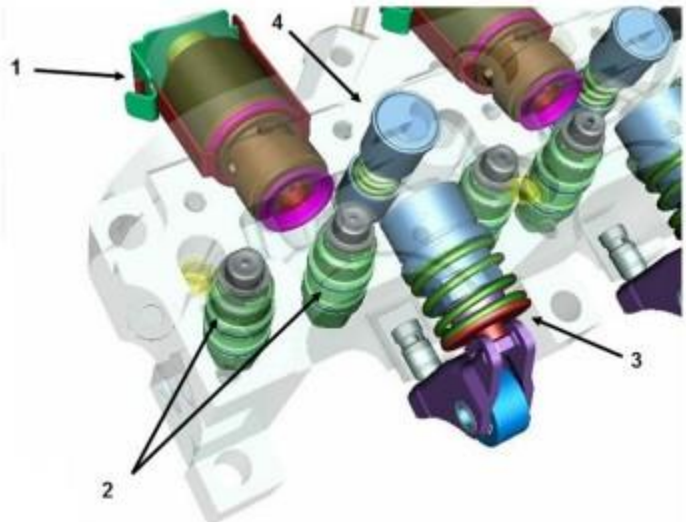

Figure 6. Uniair module components (1- Solenoid valve, 2- Hydraulic brake, 3- Upper pumping element, 4- Oil accumulator) [19].

MultiAir technology manages the torque and power delivered by the engine by varying the lift profile of the intake valves, without direct use of the throttle body. This application consists of following components:

- Single camshaft (exhaust side) with hydraulic tappets
- Uniair module (electro-hydraulic) with integrated intake tappets
- Use of the brake servo vacuum unit [19].

The MultiAir engine is characterised by a camshaft controlling the exhaust valves and an electro-hydraulic "Unair" module controlling the intake valves. The steel camshaft is fitted on the camshaft housing by means of five caps and is driven by a toothed belt. Cams are suitably oriented and profiled on the shaft. Their number corresponds to the exhaust valves plus a further four cams to control the unair module pumping elements. The front side of the shaft is pre-set for fitting a toothed pulley, connected to the crankshaft by means of a toothed belt. The timing sensor faces the toothed wheel fitted on the rear side of the shaft, while the shank drives the brake servo vacuum unit [19].

	• cylinder deactivation (switchable lost motion element or shiftung cam)	• cam phaser	• cam phaser • lost motion element (switchable tappet, cam follower, ...)	• cam phaser • shifting cam	• cam phaser • actuated inter-mediate shaft	• electro-hydr. system
						
	intake & outtake	intake & outtake	intake	intake	intake	intake
fuel reduction	approx. 7-8 %	approx. 4 %	approx. 7 %	approx. 8 %	approx. 8 %	approx. 8-15 %
Variability						
- phaising		continuous (intake and outtake)				
- valve lift	discrete: 2 stages standard and zero lift		2-3 stages	2-3 stages	continuous	continuous
- shape			compatible cam contours	independent cam contours		free shape
series production	since 1981 Active Fuel Man-agment (GM), ACC (Daimler), VCM (Honda), MDS (Chrysler), CoD (Audi,VW), ...	since 1983 commonly used by car manu-facturers	since 1989 VTEC (Honda), MIVEC (Mitsu.), VVTL-i (Toyota), VarioCam Plus (Porsche), ...	since 2006 Audi valvelift system	since 2001 Valvetronic (BMW)	since 2009 MultiAir (Fiat)

Figure 7. Different variable valve train systems in series production [20].

4. Conclusions and evaluations

The studies carried out to increase the volumetric efficiency and performance of the engines show that the multi-valve technology and variable valve timing systems are of great importance. This trend will continue in the future due to higher taxation and increasing pressure to achieve greater fuel economy and performance, while keeping lower emission rates. However, the use of high quality materials, precision surface treatment and the high costs of these systems can lead to a search for alternative replacements of valve technologies. Conducted studies show that the engines designed with a variable valve timing system have improvements in power, torque, fuel consumption and exhaust emissions. Example studies and their effects are listed in the table below.

Despite many innovations in valve systems, the automotive industry and especially the Swedish and Chinese companies continue to work on engines with variable timing and no camshaft, where each valve is controlled separately. Manufacturing engines without a camshaft is expected to bring the following advantages: lighter engine; lower friction; silent operation; lower fuel consumption; lower emissions; higher power and torque.

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