DESIGN AND DYNAMIC ANALYSIS OF A NOVEL VALVE CONTROL MECHANISM

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Abstract: *In this study, a new valve control mechanism was represented to improve the fuel consumption at part load conditions in SI engines. The mechanism was working based on the skip cycle strategy. To achieve a complete air leakage prevention at high loads and speeds, the mechanism was mounted on the poppet valves directly. The locked valve control mechanism (LVCM) was assembled to a single – cylinder research engine and driven by the engine crankshaft. The mechanism was got ready to be tested in valve disabled and valve enabled modes. This could be provided by a locking system actuated by the driving mechanism. The results of displacement, velocity and acceleration of engine and driving camshafts were represented.*

Keywords: SKIP CYCLE STRATEGY, LOCKED VALVE CONTROL MECHANISM (LVCM), VALVE DISABLED/ENABLED MODES

1. Introduction

Environment pollution has became one of the most significant phenomenon with global warming due to growing of industry. Internal combustion engines have been used for energy conversion in various areas particularly in transportation. This usage effects the atmospheric pollution by exhaust emissions and energy sources by increasing of fossil fuel consumption. Carbondioxide (CO_2) emissions are composed by complete combustion of fossil fuels involving carbon molecules. They have great impacts on formation of greenhouse effect. Nowadays there are some several limitations for (CO_2) emissions and other pollutants (HC, CO and NO_x). One of the main solution method to decrease (CO_2) emissions is to improve the energy conversion efficiency and also decrease the fuel consumption.

To reduce the fuel consumption, several researches have been made as engine systems, vehicle systems and driving systems. The maximum effective efficiency of today's SI (spark ignition) engines is about 35 % at full load [1]. If there is no improvement about the topics of knock resistance of fuel, heating value of fuel and flame velocity etc, this efficiency won't be able to increase. SI engines perform about 10 – 15 % efficiency at part load. The main reason of this deteriorating is increasing of pumping losses due to the restriction of the cross sectional area of the intake air by throttle valve used for the load control. At part load conditions, to decrease the engine power and the amount of fuel – air charge into the cylinder, throttle valve has to be more closed. Because of this reason, the pumping work increases and the engine has to work in addition to the power production.

Well – known methods to increase the efficiency at part load are; variable valve timing, stratified charged lean mixture combustion, supercharging, variable compression ratio and variable displacement. Variable valve timing and stratified charged lean mixture combustion methods have reached their top potentials. Supercharging and variable compression ratio methods are restricted for practical usage due to the knock probability of a structural problem in SI engines [2]. So the variable displacement is the least investigated method aiming to improve the fuel consumption at part load. There are two sub – types in this method : "Skip Cycle Method" [3,4] (cut off the fuel and air into cylinder and then enabling them in order with respect to decrease the work cycle frequency) and "Cylinder Deactivation" (cut off the fuel and air into a cylinder or a group of cylinder all the time)

The working principle of skip cycle method used in this study can be expressed as following descriptions : When the load of engine reduces, the fuel and air supply are disabled in sequential cycles and the amount of fuel – air charge is increased in normal cycles. (except for skipped cycles) to get the equivalent effective engine power. Cylinder deactivation causes vibrations due to sudden moment fluctuations. In contrary skip cycle method provide a soft transient regime.

Many investigations on skip cycle system are only focused on interrupting the fuel supply into cylinder for some cycles. Kutlar et al.[5] presented a new strategy for skip cycle system and valve control necessity to get expected results. They aimed to reduce the effective stroke volume of an engine at part load to skip some of the four stroke cycles by cutting off fuel injection and to decrease pumping losses when a cycle was skipped by using rotary valves in the inlet and exhaust ports. The experiment results showed BSFC (brake specific fuel consumption) was increased due to air leakage through the rotary valve at high speeds and loads. They proved that if the fuel and air leakage could be eliminated, it was possible to decrease the fuel consumption significantly at part load conditions of SI engines. To improve this case, valve controlling has been admitted as an inevitable method [5,6]

A few patented mechanisms have been represented to keep intake and exhaust poppet valves in fully closed position. These machanisms are called "Valve disabling mechanisms" and aim to control the normal operating conditions of poppet valves by using usually a locking component. All of them interrupt the force transmission sourced from engine camshaft to actuate the valve mechanism. Basshuysen invented a lock mechanism controlled by a hydraulic liquid [7]. Another mechanism replaced in rocker arm was patented by Morita[8]. A finger follower rocker arm system was represented by Diggs including an actuating mechanism to engage/disengage a pin to limit the movement of rocker arm [9] and a valve disabling switch mechanism associated with rocker arm for a multi cylinder engine was disclosed by Walsh [10]. A recent study was represented by Gerzeli et al [11]. These previous studies have some problems about bearing and assembling of mechanisms, compression of some components while moving and lack of driving systems of these mechanisms.

In this study, instead of only throttle valve or throttle valve with a rotary valve, direct control of poppet valves is used to solve the air leakage problem. This mechanism is also called "Locked Valve Control Mechanism"(LVCM). The control mechanism is driven by an external camshaft coupled to the engine crankshaft. When the poppet valves are locked by control mechanism, the air – fuel charge is carried out in normal cycle. Skip cycle is work online while the control mechanism moves freely instead of locking the poppet valves.

2. Mechanical Design of skip cycle mechanism and objectives

There are numerous mechanisms which are currently used or on designing phase. All of them have disadvantages and practicability problems.

The principle is changing the motion of rocker arm by a second pusher camshaft in BMW Valvetronic mechanism. But, there are some limitations for able to use only in overhead camshaft constructions and the components working together should be turned very sensitively.

VVTL-i and VVT-i technologies, developed by Toyota Company, have been achieved by adding a new rocker arm. Locking process is practiced with a hydraulic control pin. However control of fluid system has problems when considering of working principle of internal combustion engines.

The study of Diggs doesn't work due to the mounting problems.

The patented mechanism of Morita isn't presentable for assembling and motion of some components are troubled.

Gerzeli has recently designed a new mechanism. It was assumed to not move the serial connected springs according to the spring constants of them. The mechanism was locked up by using only one point. So, various matters have been predicted about operating life and stability. The dynamic analysis of serial spring principle, modelled by three dimensional, (Figure 1) reveals that poppet valves obviously make a displacement despite of the difference of spring constants (Figure 2)

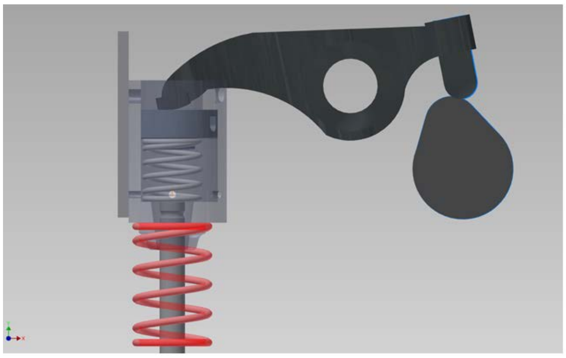

Figure 1.*Three dimensional model for the dynamic analysis*

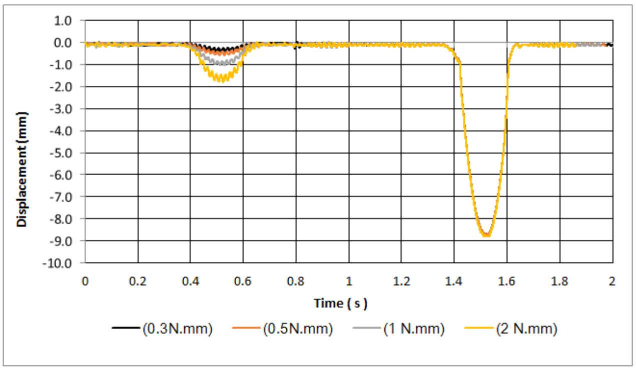

Figure 2*. Displacement values of serial springs as regards the dynamic analysis*

Due to the previous studies and their deficiencies, a new mechanism was based on the strategies defined below;

- The locked position of the system shouldn't be provided only by energy stored components. They have to be connected physically.
- The locking system have to be used through a plane with three points.
- System has to be controlled mechanically and a stability case requires.
- Practicable to present engines in market (with minimum modification)
- Practicable to overhead camshaft engines

3. Working principle of skip cycle mechanism and components

Today's internal combustion engines are working on a principle which the poppet valves are opened and closed by the camshaft connected to the engine crankshaft. In the base model, the camshaft is located on poppet valves directly also pushrod, tappet and rocker arm can be used to deliver the motion. Poppet valve return motion as for is actualized by poppet valve springs.

The original test engine used in this study is a single cylinder diesel engine of Anadolu Motor Company. The modified engine is a gasoline engine. The chosing reasons of this engine (Table 1) are being a simple model and ready to supply spare parts.

Table 1. *Technical specificaitons of the test engine*

Number of cylinders	1
Stroke volume	454 cm^3
Bore×Stroke	85×80 mm
Compression ratio	17,5:1
Intake valve diameter	32 mm
Exhaust valve diameter	27 mm
Intake valve lift	10 mm
Exhaust valve lift	10 mm
Intake valve opening	16^0 CA BTDC
Intake valve closing	40^0 CA ATDC
Exhaust valve opening	40^0 CA BBDC
Exhaust valve closing	16^0 CA ATDC
Valve overlap duration	32^0 CA Symmetric
Pushrod length	145 mm
Valve clearance in cold engine	0,2 mm (Intake and exhaust)

The skip cycle strategy developed by Kutlar is similar to the other systems, which disable the cylinder, also can be practiced for single cylinder internal combustion engines. In a conventional engine, two rounds of the crankshaft is corrosponded to a cycle. In the skip cycle method; after the cycle which includes power production,any work transfer can't be obtained in the sequential cycle. To carry out this by pass,injection and ignition are cut off in the skipped cycle. By this way, work transfer can be achieved with four crankshaft rotations. Only fuel cut off is not sufficient to decrease the pumping losses. The air flow into cylinder at intake process should be prevented additionally.

3.1. Disabled mode of poppet valve

The pusher pin series is activated by the control camshaft. When the pusher pin situates into lock body and locked position, spring retainer will be locked with cylinder head. In this case, lock body is free standing. Spontaneously, the motion from the engine crankshaft system is transmitted to the rocker arm by the help of pushrods and rocker arm moves along downward. Due to the freedom of lock body, the rocker arm activates the lock body in the spring retainer vertically. The feedback of the rocker arm is carried out by mechanism spring which locates in the locking system. So, the spring retainer component is motionless and the valve motion is disabled in the locked position. (Figure 3)

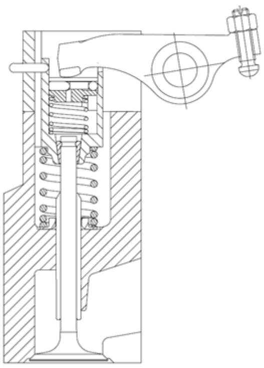

Figure 3. *Disabled mode of poppet valve*

3.2. Enabled mode of poppet valve

The pusher pin series is activated by the return camshaft. When the pusher pin situates into the lock body and unlocked position, spring retainer is pulled out from the cylinder head and be locked with the lock body by three points. Spontaneously, the motion from the engine crankshaft system is transmitted to the rocker arm by the help of pushrods and the rocker arm moves along downward. Due to the connection between lock body and spring retainer performed by the position of pusher pin series, rocker arm activates the spring retainer vertically. The poppet valve is free standing now with respect to connection of spring retainer and poppet valve (Figure 4)

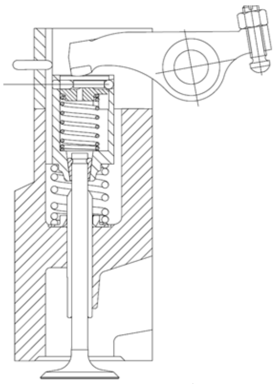

Figure 4. *Enabled mode of poppet valve*

3.3. System components

3.3.1. Cylinder head

Rocker arm, poppet valves and valve springs are normally beared on the cylinder head. Hence the skip cycle mechanism is located on the poppet valves, cylinder head bears the mechanism too. For this reason, cylinder head should be enhanced only 32 mm. One of the main advantages of the system are to locate the mechanism on the cylinder head of the test engine and able to control the mechanism with only small displacements on the pushrods. (Figure 5)

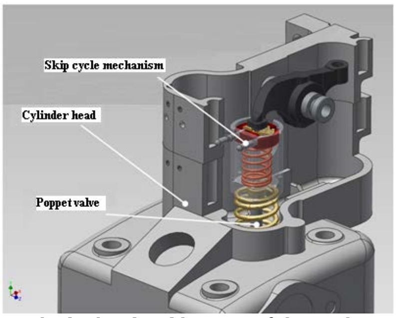

Figure 5. *Cylinder head and location of skip cycle mechanism*

3.3.2. Spring retainer

It is a component used to mount the poppet valves to lock body (Figure 6). It plays a significant role on mounting the lock body and other components also at the locked position. Preventing of axial rotation is occured by a special profile. The bottom side of profile is identical with the original spring retainer. Due to the six oil venting hole, no oil will accumulate into the spring retainer.

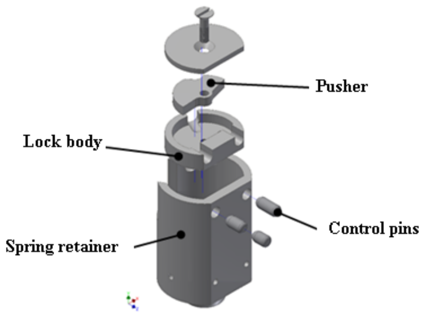

Figure 6. *Spring retainer and its components*

3.3.3. Lock body

Lock body takes in charge the mounting of pusher and pins also of all the components with respect to locked and released positions.

3.3.4. Pusher

It is the component used to adjust the position of control pins and sphere locking system. Pusher is the most important part of this mechanism owing to get the regulation ability, the position of locked and released cases. That can be carried out by the transmissions of mechanism motion from control camshaft with a calculated special profile to other system components. The material selection and profile calculations become crucial hence the pusher is exposed to many variable loads. In Figure 7a, the positions of loads that is necessary for the fatigue analysis with 1.000.000 cycles of pusher component made of St50 can be seen. The FEM mesh structure used in fatigue analysis can be seen in Figure 6b. The result of the analysis indicated that the maximum effective stress occured as 115 MPa.

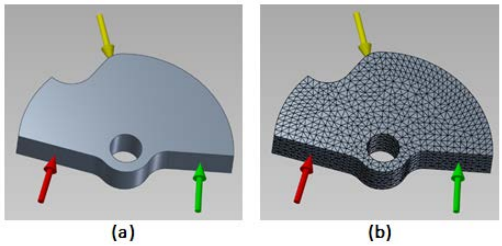

Figure 7. *a.Forces on the pushrod, b.FEM mesh structure used for fatigue analysis of pusher*

3.3.5. Control pins

They arrange the cases of locked and released positions of the skip cycle mechanism. It transfers the motion of external control camshaft to the pusher. Poles of them were designed as a parabolic profile as therefore the centering could be made automatically for the possible postponements.

4. The synchronization and control of skip cycle mechanism

The poppet valves are disabled and enabled according to the cycle mode, normal or skipped. Hence, the locked and released positions must be arranged as far as the motion of rocker arm which drives the poppet valves. Rocker arm is moved off by the intake or exhaust camshaft which are settled on seperated locations. The engine camshaft connects to the engine crankshaft with a gear at the ratio of 1/2.

The locked and released positions of control pins used in skip cycle mechanism are adjusted by control camshaft.The control camshaft is actuated by a gear – belt system, connected to the engine crankshaft at the ratio of 1/2. Thus, the gear – belt mechanism carries out the synchronization of the motion. Since the direction of crankshaftand control pins are different, the motion direction is changed as 90° by the angular gears. (Figure 8)

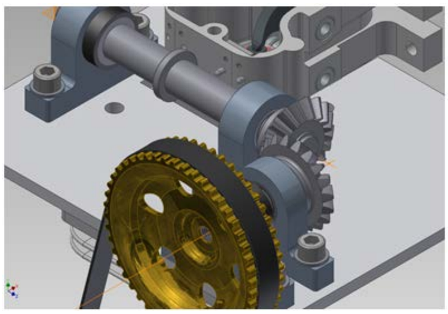

Figure 8. *Gear – pulley and its motion components*

To detect the profile of control camshaft, the polynomial curves were preferred to obtain the displacement, velocity and acceleration characteristics.(Figure 9) While selecting the degree of polynomial, 3-4-5 polynomial was used due to the convenience of manufacturability and motion sensitivity also being close to cycloid curves.

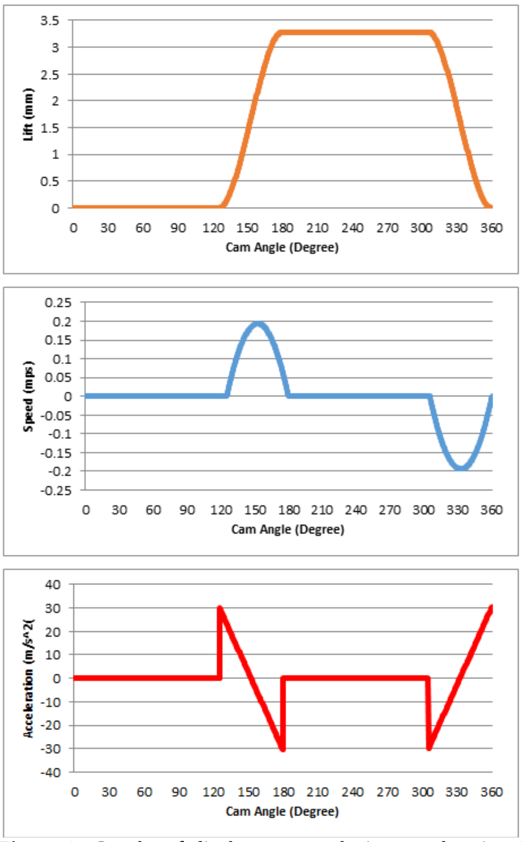

Figure 9. *Graphs of displacement, velocity, acceleration for the control camshaft*

$$y = 1 - 100\theta^3 + 150\theta^4 - 6\theta^5$$

$$\dot{y} = -30\theta^2 + 60\theta^3 - 30\theta^4$$

$$\ddot{y} = -60\theta + 180\theta^2 - 12\theta^3$$

The control pins move off between locked and released positions with the help of control and return camshafts. Hence, the control and return camshaft profiles must be compatible to the dynamic equation of the engine camshaft. In Table 2, the synchronized positions of intake and skip cycle control camshafts are shown.

Table 2. *Control camshaft : Synchronized angle positions*

Position of intake camshaft	Position of control camshaft	Cycle mode
0°– 110° (constant)	0°– 55° (constant)	Normal
110°– 180° (rise)	55°– 90° (constant)	
180°– 250° (fall)	90°– 125° (constant)	
250°– 360° (constant)	125°–180° (Start of locking)	
0°– 110° (constant)	180°–235° (Running on locking)	Skipped
110°– 180° (rise)	235°–270° (Running on locking)	
180°– 250° (fall)	270°–305° (End of locking)	
250°– 360° (constant)	305°– 360° (constant)	

5. Conclusion and Future Work

The design and analysis process of the prototype of skip cycle mechanism have been completed. It is thought to test the responsibility of the mechanism under thermal stress particularly at high speed and variable loads.

For the future work, engine tests of each stragety (NS and NSS) will be carried out to define the efficiency of that mechanism with an adaptable electronic control unit.

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