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Increasing the Performance of Existing IC Engines by Free Valve Actuation Technology

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ABSTRACT

In this current generation, the efficiency of gasoline engines is around 50%. This isbecause of many losses within the system. The most important losses are because of moving parts. Moving parts comprises piston, cams, rod etc. Investigations are being conducted to cut the losses to enhance efficiency. One such outcome is that the free Valve Mechanism which uses poppet valves operated by means of pneumatic actuators rather than cams. Actuators are used to open and shut the valves and control combustion within each cylinder and hence improving the efficiency.
Keywords : Pneumatic Actuators, Efficiency, Free Valve Technology, Poppet Valves

I. INTRODUCTION

An actuator is a part of theapparatus that is in chargeof movement and control of a system, like opening a valve.

The working of an actuator is based on a control signal and a source of energy. The control signal is comparatively of a low energy and might be voltage or current, hydraulic or air pressure. When the actuator receives a control signal, it responds by converting the signalinto mechanical motion. Actuation is a mechanism by which a control system acts upon a given environment.

A valve actuator is an instrument used for opening and closing a valve. Manually operated valves require physical interference to adjust them using geared mechanisms close to the valve base. Power-operated actuators, using gas pressure, liquid pressure or electric current, valves to be adjusted by very small tolerances, or allow rapid action of large valves. Used for the automation of industrial valves, actuators can be seen in all kinds of process plants. They are used in sewage treatment plants, power plants, Refineries, mining and nuclear processes, food factories, and pipelines. Valve actuators play a major part in automating process control. The valves to be automated contrast both in design and sizes.

In an engine with a Pneumatic valve actuation system, valve movements are controlled independently with respect to crankshaft rotation. In conventional Internal Combustion (IC) engines, the timing of intake and exhaust valves is controlled by the shape and angle of cams. Engineers need to select the best timing among fuel economy, emissions and torque, to design the shape of the cam. The optimization of cam profile is possible only at one engine speed. But I.C. engines in automobile operate over different speed and load ranges. 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 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 Variable Valve Actuation.

The Valve Actuation which is a trail to electromechanical enginesystem 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 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 Pneumatic system. The main aim of this project is to increase the performance of existing IC engine by reducing mechanical movement of parts and losses associated with the engine. In addition to that Arduino is used to control the valves of the engine with the help of valve timing programming.

II. LITERATURE SURVEY

A literature survey is been conducted to find if any free valve technology paper work has been carried out on similar ground of present work. Several valve actuation design and analysis conducted by few individuals were found but those were dependent on other factors and parameters. The summary of those reports are as given below.

A. S. More, [1], [2009], this work deals with the study of valve train. This journal give various information such as valve displacement, valve velocity etc.

Junfeng Zhao B.A.Sc, [2], [2007], this journal gives an idea of variable valve actuation and equipment related to it.

V. Ganesan, [4], [2001], this book gives an detailed insight of an internal combustion engine.it contains all the explanations related to valve train,cams etc and also their working in detail.

It is observed that many literatures are available on similar grounds of present work. However only few important articles are discussed under this section, remaining journals related is listed in reference.

III. GEOMETRY

The geometry of the model used for the project is as shown in Figure 3.1 and 3.2. It consists of Pneumatic actuator, valves, Piston and connecting rod.

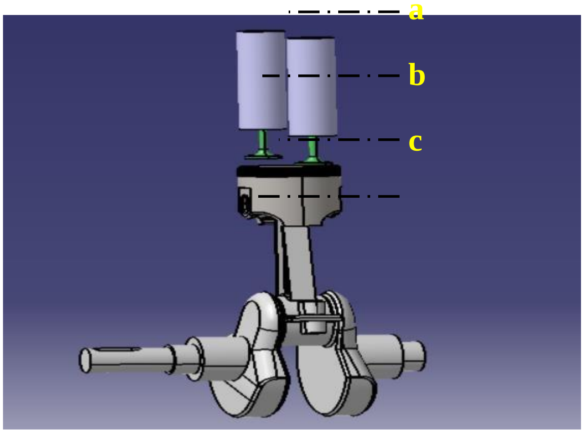

Figure 3.1

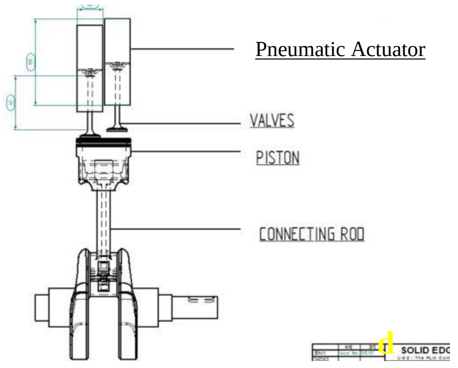

Figure 3.2

Figure 3.1 and 3.2: Assembled view of free valve mechanism

a. ***Pneumatic actuators:*** Pneumatic actuators are mechanical devices that use compressed air acting on a piston inside a cylinder to move loads along a linear path.
b. ***Valves:*** Valve travel distance is the distance the plug or stem moves to go from a fully closed to a fully open position. It is also referred to as Stroke.
c. ***Piston:*** It is a moving component that is contained by a cylinder and is made gas-tight by piston rings.
d. ***Connecting rod:*** It is a part of a piston engine, which connects the piston to the crankshaft.

3.1 Pneumatic actuator

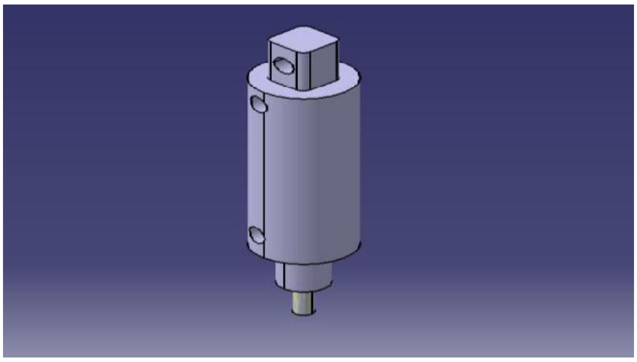

Figure 3.3 : Pneumatic actuator

Figure 3.3 shows the Pneumatic actuator which is used in this paper work.The actuators are being used is pneumatic actuator. This pneumatic actuator is a double acting cylinder type.

3.1.1 Design specification of Pneumatic valve

Bore diameter= 32 mm

Stroke length = 25 mm

3.2 Actuated valve

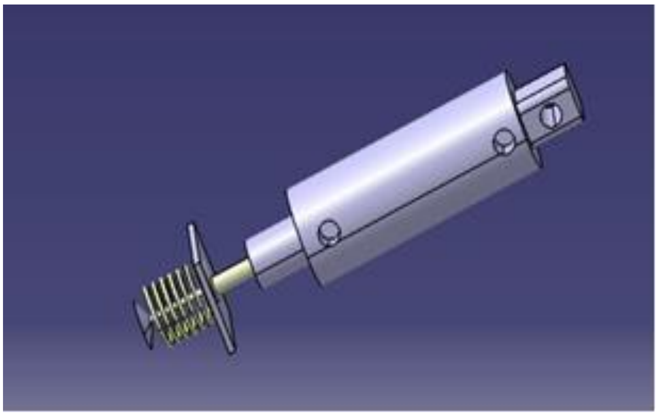

Figure 3.4 : Spring valve actuation

Valve travel distance is the distance the plug or stem moves to go from a fully closed to a fully open position. It is also referred to as Stroke. It is basically the distance by which the valve opens or closes during the stroke cycles of an engine. This value varies from engine to engine but considering a standard engine, one value is arrived at. It is very important for us to determine the travel distance of the valve in order to determine the force acting on the valve so that we can adopt methods to minimize the energy spent for this process thereby increasing the efficiency of the engine. Based on the measurements taken from standard and preserved engines, the valve travel is found to be around 10 millimeters.

Valve forces are anvital parameter in determining the loads acting on the valves during their operation. There are various types of forces acting on valves, namely holding force and thrust force. Holding force is the force required to hold the valve in position while running and thrust force is the force applied on the valves in order to facilitate their opening and closing. The following formulae can be used to calculate the force acting on the valves to facilitate their operation.

Kinematic motion of engine valves are governed by valve actuating mechanism generally push rod mechanism. This mechanism is driven by motion of crankshaft of engine and as a result of which engine valve continuously opens and closes the ports which control the flow of gas through ports. Engine valve is opened by valve actuating mechanism just before the beginning of exhaust stroke so that exhaust gases are blown out and it is by compressed spring just after the beginning of suction stroke. Thus the valve is continuously under tension and compression alternatively which lead to fatigue failure alternatively which leads to fatigue failure.

3.2.1 Design specification of Actuated valve

Valve Diameter of valve port (D_p) = 21 mm
Valve angle (θ) = 45
Diameter of valve head (D_v) = 27 mm
Thickness of valve disk (t) = 2 mm
Diameter of valve stem (D_s) = 12 mm
Maximum valve lift (h_{max}) = 10 mm

IV. FORCE CALCULATION

The following are the values obtained with respect to our engine:
Bore Diameter D = 53.5 mm
Length of stroke L = 54 mm
Engine Speed N = 7500 rpm

4.1. Calculation for forces acting on poppet engine valve:

The calculation for forces acting on poppet valve for inlet valve and outlet vlave is as shown below:

4.12. For inlet valve

Force required to open the valve

$F_{open} = Fi + Fl + Fg$ -------------- (1)

Where, F_i = Initial spring force
F_l= Force required to lift the valve
Fg= Gas force

Mathematically,

$\boldsymbol{F_i = \frac{\pi}{4} \times D_v^2 \times P_s}$------------ (2)

Where, Ps = Suction pressure = 0.002 to 0.004 N/mm^2

$\boldsymbol{F = K \times h_{max}}$ ----------------- (3)

Where K= spring stiffness = 20.3909 N/ mm

$\boldsymbol{F_i = \frac{\pi}{4} \times D_v^2} \times P_g$------------------ (4)

Where P_g = gas pressure = 0.35 to 0.40 N/mm^2

Substituting equation (2),(3) and (4) in equation(1),
Fi = 0.6729N
Fg= 89.727N
Fl = 203.909N
Fopen = 294.3089N

4.13.For outlet valve:

From equation (1),
Where, Fi = 0.9424N
Fl = 203.909N
Fg = 125.66N
Fopen = 330.515N

The force required to lift and open the valves during their operation is hence calculated and thus from the values obtained, can determine which type of actuators to be used for this application.

But for determining the type of actuators, need to consider the most important parameter, which is temperature. need to determine the temperatures generated at dominant engine parts in order to determine the type of actuators to be used because with increase in temperature, some actuator properties like that of electromagnetic actuators tend to change and ultimately tend to fail.

Average temperatures for operation of the valves are between 300- 400°C for intake valves and 500-900 °C for exhaust valves. Also from mechanical point of view, the valves are strongly solicited because the operation at very high speeds, which can reach values of 600 m/s. The corrosion requirements are the most important ones, because the high thermal working conditions favour the acids formation, which act on the materials microstructure. At these solicitations adds the abrasive wear phenomena caused by hard particles. The temperature-based selection of actuators becomes very important in this case since the actuators are sensitive to temperature.

V. CALCULATION FOR VALVE TIMING OF POPPET ENGINE VALVE

Engine under consideration is high speed engine and as a result of which the exhaust valve will open 55 before Bottom dead center and will close 20 after top dead center. This being true theoretically but will deviate from it under practical situation whose consideration is beyond the scope of this research paper.

Total angle of rotation of crank shaft when exhaust valve is open is,

θ_1 = 55 + 180 + 20

= 255

Total angle of rotation of camshaft when exhaust valve is open

θ_1 =255/2

= 127.5

= 2.224 radians

Speed of camshaft is given by,

N_{cs} =7500/2= 3750 rpm

Number of rotation of camshaft per second,

N_{ps}=N_{cs}/60=3750/60

= 62.50 seconds

Time required by camshaft to complete one rotation,

T_{1r} =1/N_{ps}=1/62.50

= 0.016 sec

Time required by camshaft to complete rotation of one degree,

T_{1d} =T_{1r}/360

=0.016/360

= $4.44*10^{-5}$ seconds

Time for which the exhaust valve is open is given by,

$T_{open} = \theta_1 \times T_d = 255 * 4.44*10^{-5}$

= 11.32×10^{-3} seconds

Cycle time for poppet engine valve to once open and close is given by,

$T_{total} = 360 \times T_{1d}$

= $360 \times 4.44\times10^{-5}$ seconds

= $16*10^{-3}$ seconds

Where ,

$T_{total} = T_{open} + T_{idle}$

Where,

T_{idle} = Time for which valve is closed and is in idle state which means that it neither opens nor close during this time.

Therefore,

$T_{idle} = T_{total} - T_{open}$

Substituting values in above equation we get,

$T_{idle} = 16\times10^{-3} – 11.32\times10^{-3}$

= 4.67×10^{-3} seconds.

Based on above calculation the condition of poppet engine valve with change in time for 360 rotation of camshaft is as shown in Table 5.1.

Table 5.1 Poppet valve condition with time

Sl. no	Span of time (seconds)	Poppet Engine valve condition
1.	0 to 4.67×10^{-3}	Valve is Idle
2.	4.67×10^{-3} to 6.641×10^{-3}	Valve opens
3.	6.64×10^{-3} to14.03×10^{-3}	Valve is open and Idle
4.	14.034×10^{-3} to16×10^{-3}	Valve closes

Based on calculation of various forces acting on poppet engine valve, its condition with time and magnitude of forces acting on it is as shown in Table 5.2.

Table 5.2 Forces on Poppet valve with time

Sl. no	Span of time (seconds)	Poppet Engine valve condition	Magnitude of force acting on valve stem head (Newton)
1.	0 to 4.67×10^{-3}	Valve is Idle	0
2.	4.67×10^{-3} to 6.641×10^{-3}	Valve opens	330.11
3.	6.64×10^{-3} to14.03×10^{-3}	Valve is open and Idle	330.11
4.	14.034×10^{-3} to16×10^{-3}	Valve closes	15.08

When poppet engine valve opens nature of force acting on its valve stem is compressive in nature and time during which it closes nature of force is tensile in nature, which leads to fatigue loading of poppet engine valve. This loading of poppet engine valve is unidirectional in nature. Maximum valve lift is found to be 10 mm. The unidirectional displacement of poppet engine valve is as shown in Table 5.3.

Table 5.3 Displacement of Poppet valve with time

Sl. no	Span of time (seconds)	Poppet Engine valve condition	Magnitude of Displacement of poppet engine valve (mm)
1.	0 to 4.67×10^{-3}	Valve is Idle	0
2.	4.67×10^{-3} to 6.641×10^{-3}	Valve opens	10
3.	6.64×10^{-3} to14.03×10^{-3}	Valve is open and Idle	0
4.	14.034×10^{-3} to16×10^{-3}	Valve closes	10

VI. TEST RESULTS

The results obtained through Morse test is been tabulated in this section.

6.1Using Morse test the results determined are as follows:

First the engine is rigged onto the dynamometer and all the necessary connections are made to carry out this test. In this test,the engine is first run at the required speed and calculated amount of fuel is used and the output is measured.

Table 6.1 : Conventional Engine

EFFICIENCY (%)	BRAKE POWER (BP)	INDICATED POWER (IP)
46.88	0.57	1.21
47.20	1.03	2.18
47.50	1.54	3.24
48.00	2.05	4.27

Table 6.2 : Fully variable actuation Engine

EFFICIENCY (%)	BRAKE POWER (BP)	INDICATED POWER (IP)
58.30	0.62	1.06
58.70	1.23	2.09
59.44	1.64	2.76
61.00	2.26	3.70

VII. CONCLUSION

With the help of Morse test, we can find the indicated power of the engine. Elimination of mechanical elements by replacing them with the pneumatic actuators is done. This increases the efficiency of the engine by around 15% by reducing the mechanical losses.

Further, as future scope of the work, pneumatic actuators can be replaced by electromagnetic actuators to improve the accuracy of valve actuation. Also system can be automated using Raspberry Pi and crankshaft position sensors to make the system more efficient.

VIII. ACKNOWLEDGEMENT

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