International Journal of Scientific Engineering and Technology
Volume No.4 Issue No.3, pp : 178-181

(ISSN : 2277-1581)
01 March. 2015

Design of Innovative Engine Valve: Background and Need

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Abstract: This is part one of the paper on conceptual design of an engine valve. This paper describes the background and the need of an engine valve for an internal combustion engine. The present state of the engine valve technology and the innovations incorporated in its design has been described. The paper presents the conceptualization of an innovative valve train aiming at lesser number of components, reduction in friction and wear, proper sealing, and trimming down pumping losses. The need of these objectives have been identified and established. The next part of this paper describes the various geometric designs of valve trains that have been conceptualized and compared by using the Magnetorheological Fluid (MRF) and electromagnets.

Keywords: Innovative Design, Variable valve actuation mechanism, cam-less engine valve, Magnetorheological fluid.

I. Introduction

Today, more than 70% of passenger cars utilize gasoline (petrol) as their prime chemical energy source. The major attractions of these spark ignition engines are their high specific power (power/weight ratio) and the rate at which they accelerate the vehicle. The performance of these engines is largely determined by proper operation of their valve train arrangement. The engine valve trains control the gas flow to and from cylinders. The most commonly used valve train is shown in Fig. 1.

Fig. 1 shows a number of friction interfaces such as cam/pushrod, pushrod/rocker-arm, rocker/rocker-arm shaft, rocker-arm/valve and valve/valve-guide. Due to many friction interfaces, approximately 25% of total engine friction losses are attributed to the valve train sub-system.

Teodorescu et al. performed experiments to study the contribution of different components such as rocker arm, push rod and cams in the total friction losses occurred in the valve train having geometry similar to that shown in Fig. 1. They measured friction components of valve train directly from a fired single cylinder engine and concluded that the friction in the rocker arm bearing is dominated by boundary friction mechanism. They noted that combined friction between cam/push-rod/bore represents 85 to 90% of the total friction energy dissipated in the valve trains. As per their study, friction between valve-stem/guide was only 1.5 -2.0% of the force acting on the valve stem.

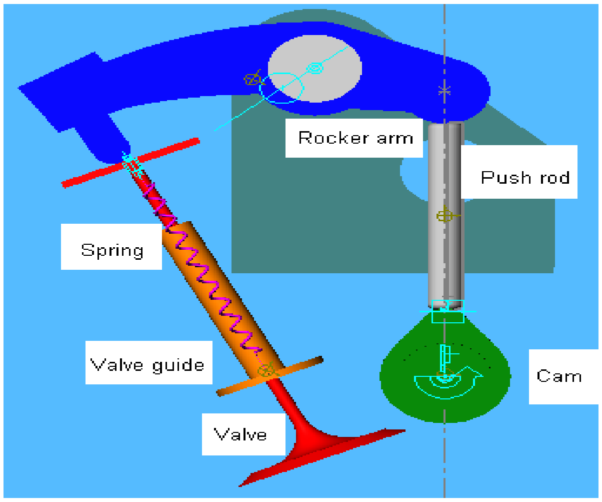

Figure 1: Cam with pushrod valve train mechanism

The components of valve train, shown in Fig. 1, often experience higher acceleration, larger impact load, more friction and greater wear losses on increasing engine speed.

To reduce the sensitivity of engine-speed on the performance of valve train, often direct overhead cam (DOHC) mechanism, as shown in Fig. 2, is preferred. However, this mechanism faces lubrication problems and may result higher friction and wear losses.

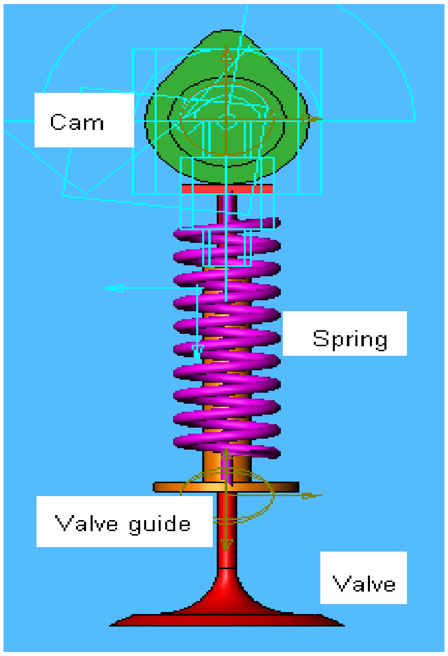

Figure 2: Direct Overhead Cam valve train

Michalski et al. performed experimental study on direct overhead cam follower valve train. They experimentally measured the values of surface stresses, friction moment, follower wear, cam lobe wear and cam flank wear and concluded the material and its surface hardness play important role in reducing friction and wear of DOHC.

Liou et al. proposed a variable pressure damper to adjust the friction force on the valve spring to eliminate the valve bounce at higher speed operations.

In addition to valve train friction losses, part load efficiency of the gasoline engine is a drawback. Throttling, a process to control the speed and load conditions, is responsible for low part load efficiency of gasoline engine. A major disadvantage of throttled engine is pressure loss in the engine manifold. This requires energy pumping (termed as 'pumping losses', as shown in Fig. 3) to increase pressure of inhaled fresh air. These pumping losses are high (as shown in Fig. 3 by the area covered by red thick line) at low load (partial opening of throttle valve), medium at medium load (as shown in Fig. 3 by area enclosed by pink thick line) and low at wide-open-throttle (high load).

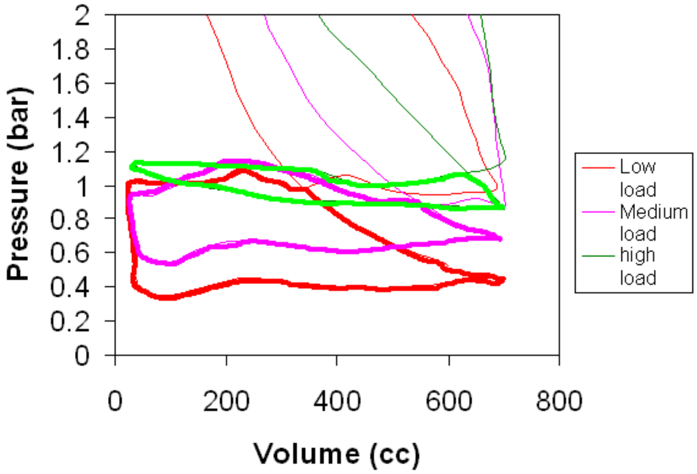

Figure 3 Engine pumping losses at low, medium and high load on engine [17]

To reduce pumping losses, a need for mechanism which varies the valve lift as a function of operating speed is often experienced. The gasoline engine operating at high speed requires different valve settings than the same engine working at low speed. High lift of intake valve is desirable in order to achieve cylindrical filling and excessive power. On the other end, at low engine speeds, small lift is desired in order to increase air velocity as it passes through the valve, which leads to a faster burn rate. Variable valve lift mechanism is one way to overcome this contradiction.

To reduce the pumping, friction and wear losses, a throttle-less engine in which inlet valve itself controls the charge inducted in engine cylinder is preferable. A conceptual design of throttle-less engine cylinder is shown in Fig. 4.

In fig. 4, a valve that changes its shape due to variation in stiffness is illustrated. Low stiffness of valve is required to induct fresh charge during suction stroke, while high stiffness of valve is desired to seal the valve-port. The advantages of the valve arrangement shown in Fig. 4 are:

+ Lesser number of components compared to valve trains shown in Figs 1 & 2.
+ No friction loss. However, controller which varies the stiffness of valve may require some power.
+ No wear. Therefore high durability of valve train mechanism.

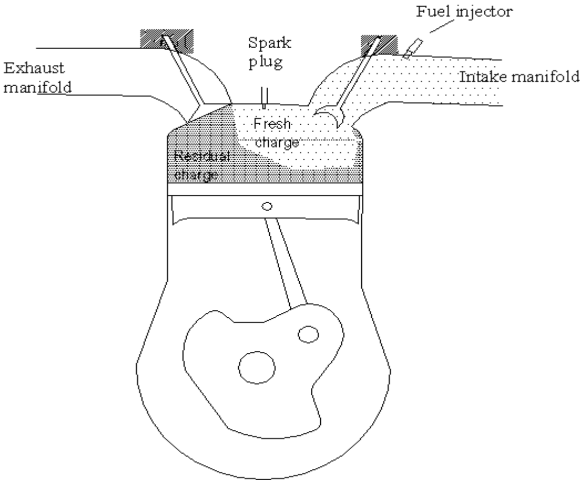

Figure 4: Variable stiffness valve fixed in engine block

The aim of the present research is to develop a valve train mechanism such as shown in Fig. 4.

II. Background

Design of engine valve trains has evolved since last twenty years. In order to understand the effect of higher speed and higher output engines on vibration behaviour of valve trains, Lee and Patterson developed a non-linear five-degree-of-freedom model treating spring as a distributed parameter system. Paranjpe and Gecim [5] compared friction loss among five types of valve trains which are shown in Fig. 5.

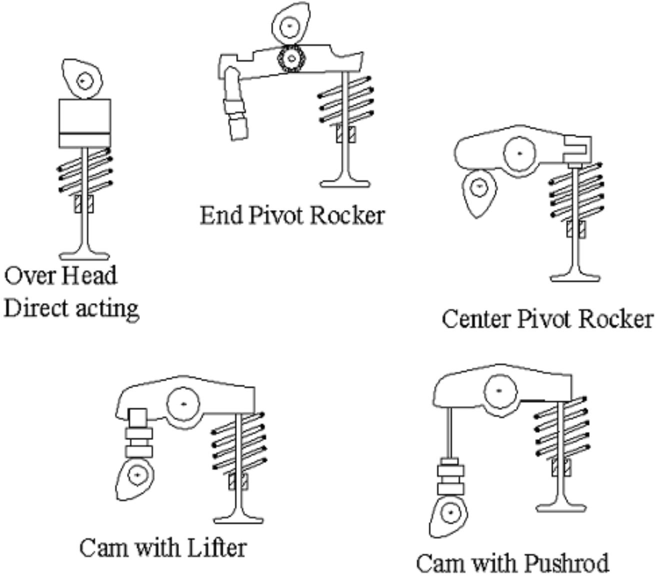

Figure 5: Various valve train arrangements

For true comparison different valve trains were made equivalent by maintaining the same valve lift, and the same no-follow speed. They found lowest friction with direct acting overhead camshaft (DOHC) valve train. Mufti and Priest performed experimental and theoretical study on DOHC with different lubricant formulations, with and without friction modifiers. They observed fuel economy benefit using friction modifier lubricant formulation.

Recent trend of valve design is reducing the mass of reciprocating components. Generalized thinking is that lower masses reduce inertia and therefore friction losses will be reduced. Fukuoka et al. developed a lighter valve DOHC train using an aluminium tappet, an aluminium spring retainer and a thin sintered shim to reduce the inertia loading on cam. Cost effective Fe-spray coating was selected by authors to ensure wear resistance of valve components. By utilizing these parts, they reduce inertia mass by 28% and they concluded a 40% reduction in friction. Kaenel et al. preferred weight reduction of valve using 0.5 mm to 1.0 mm wall thickness of stem. They suggested filling of hollow valve areas with liquids to improve the heat distribution in order to reduce temperature peaks in critical areas. Development of lightweight hollow valves was major target of research performed by Gebauer and Gavrilescu. They optimized welding and manufacturing operations to develop a deep drawn hollow valve for automotive engine operation.

Ashhab et al. researched on camless intake process that controls cylinder air charge with the intake valve motion, reduces pumping losses and thus increases fuel economy. Shaver et al. utilized variable valve actuation to modulate the valves to achieve homogeneous charge compression ignition (HCCI). Chang et al used an independent electromechanical device to enable variable valve timing in internal combustion engine. Such valve train requires very sophisticated control to reduce the intensity of valve impact on valve seat. Generally high valve impact creates unnecessary wear of valve and valve-seat. Peterson and Stefanopoulou presented designed a controller that tunes a nonlinear feedback to achieve impact velocities of less than 0.1 m/s. They used eddy current to measure the valve position and microphone to measure the sound intensity.

Hirani et al has employed the MRF in the operation of brake and have determined the effectiveness of MRF in various other applications. The design of the innovative engine valve employs Magnetorheological fluid and electromagnets to vary the valve-lift.

III CONCLUSION

The paper presents current state of the engine valve technology. The issues concerning the optimum performance of the engine has been discussed and the need of an innovative engine has been identified and established. The next part of the paper presents three conceptual designs of the valve train for an internal combustion engine.

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