Modelling of Push Rod Type Valve System for Minimization of Frictional Losses

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ABSTRACT

The mechanical systems involving tribo pairs are subjected to friction and wear requiring tribological analysis for its proper design. The main emphasis in the design of such mechanical systems is on the minimization of frictional losses and wear. The push rod type cam and follower mechanisms is one such mechanical system that causes high frictional losses specifically when used in the internal combustion engines. In the present research work modelling of push rod type valve system for the minimization of frictional losses has been carried out. Different methods of minimizing friction in push rod type valve system is presented.

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Key words: Tribology, engine valve, frictional torque, cam and follower.

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INTRODUCTION

The overall running cost of a mechanical system is dependent on the frictional losses incurred during its operation. The amount of energy lost in overcoming friction is very significant. The reduction in friction may minimize this energy loss resulting in substantial savings. The reduced friction also affects the wear of the components affecting their useful life. The push rod type valve system also experiences friction between its tribo pairs and thus requires tribological considerations for minimization of friction. This paper presents the modeling of friction of push rod type valve system and presents different means of minimizing the friction.

The friction measurement is necessary for the analysis of the valve system. The method developed by Banisad and Emes [1] used strain gauges for friction torque measurement. They used direct acting type valve train with flat follower in their analysis. Strain gauges were mounted on the sprockets of cam gear. Suitable spoke width was used to give best possible signal proportional to the friction torque and full Wheatstone bridge was used to measure strain. Static and dynamic calibration was carried out to find an accurate correlation between the applied torque and the output voltage. Motored engine setup was used to measure friction. Motor drives the crankshaft and cam belt connects crankshaft pulley to the cam sprockets. Signal from strain gauges are then processed to get frictional torque. Results show that the variation of torque with camshaft speed contained characteristic waveform with positive and negative parts, average of which gave friction torque. As speed increased friction torque decreased.

Several methods are used to reduce the valve train friction. Fukuoka et al [2] used the method of lighter parts. They replaced tappet, spring retainer and shim of direct acting valve train. By utilizing these parts, valve train inertia mass was reduced by 28%. Cam profile and valve spring specifications were redesigned fully to employ the reduced inertia mass to reduce friction. The overall friction loss was reduced by 40%. To make a lighter tappet, an aluminium alloy was used to replace the traditional base material of carburised Cr-Mo steel. The high temperature strength, the forgeability, the machinability used as criteria to select Al-Si eutectic alloy FMS707. New casting technique was also developed. Valve tip contact portion where maximum stress occurs was redesigned and optimization of wall thickness was carried out. The spring retainer was redesigned, as in the case of the tappet, to replace the Cr-Mo carburized steel with the lighter and high strength aluminium alloy considering material properties and loading condition of the engine. To optimize the lighter design of the valve train to the lowest possible valve spring load, corrective redesign of the cam profile was made. Cam profile modification and valve spring redesign were performed to achieve equivalency in the maximum input load of the valve train and cam working angle and valve lift area.

Soejima et al [3] suggested a method of improving lubrication condition between cam and follower by supplying lubricating oil from cam surface oil hole. To evaluate the performance of cam lobe oil hole, the oil hole of the cam specimen was arranged at various positions such as base circle, flank and nose. They conducted test on their setup by supplying oil from one hole at time and checked scuffing performance. They observed that cam oil hole is an effective mean to improve lubrication. The largest effect is with forward oil supply from the oil hole located on the flank corresponding to the valve opening.

Fujiki et al [4] of Nissan Motor examined worn valve seats and inserts to obtain a fundamental understanding of the wear mechanisms. The results were used to develop new valve insert materials. Current seat insert materials have composition of 1.5%Mo, 5%Co, 1.5%Ni, 15%Pb, 0.7%C with balanced Fe. Intake seat and inserts are generally not exposed to high temperature. After examining worn seats it was observed by them that wear occured due to delamination and heat transfer problem from depositions. Taking into account these results a new intake insert material was developed consisting of 4.7%Mo, 5%Cu, 1.4%C with balanced Fe. Exhaust valve seats and inserts are exposed to high temperatures and showed unacceptable wear when unleaded petrol was used. A new exhaust valve insert material was developed having composition 12%Co, 1.2%Cr, 5%Mo, 1.2Ni, 18%Pb, 0.65%C with balanced Fe. Similar tribological considerations are used in the design and analysis of journal bearing, seals, brakes, gears, valves etc [5-60].

FRICTION REDUCTION IN VALVE TRAIN

Reducing friction losses in valve train can be considered as effective means to improve fuel economy. The following methods are proposed for the minimization of friction:

1. HOLLOW VALVES

The valve spring is designed in such a way that it should provide sufficient force on inertia mass of valve mechanism to keep follower always in contact with cam. Reduction of inertia mass will lead to reduction of force required by spring.

One of the methods to reduce inertia mass is to use hollow valve. The friction reduction can be predicted by replacing solid valve of push rod valve train by hollow valve. These hollow valves can be produced by the conventional and non-conventional manufacturing methods. In conventional methods gun drilled method has evolved into three types: tube to solid, draw in and hollow head valve as shown in figure 1.

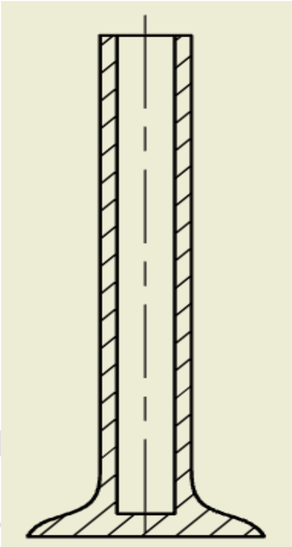

Figure 1 Hollow valve

Considering a given reduction in valve mass, the spring stiffness is redesigned accordingly at maximum speed.

We know that,

$$F_p = \frac{J.\ddot{\theta} + F_v.L_2}{L_1}$$

But, $$W = F_p + m_t.a_c$$

Hence, $$W - m_t.a_c = \frac{J.\ddot{\theta} + F_v.L_2}{L_1}$$

For zero contact load at the point of maximum negative acceleration, we can write,

$$0 = \frac{J.\ddot{\theta}}{L_1} + (S + F_s + m_v.a_v)\frac{L_2}{L_1} + m_t.a_c$$

Solving above equation for F_s will give minimum spring force required to just avoid follower to lose contact with cam at maximum operating speed. Then, required stiffness is given by,

$$K_1 = \frac{F_s}{L}$$

where, L is the lift at the point of maximum negative acceleration.

Calculation of spring stiffness for hollow valve gives its value equal to 18.77 N/mm. By using this stiffness corresponding to mass of hollow valve, average friction torque for different speeds is calculated. Comparative results for hollow and solid valve are shown in fig. 2.

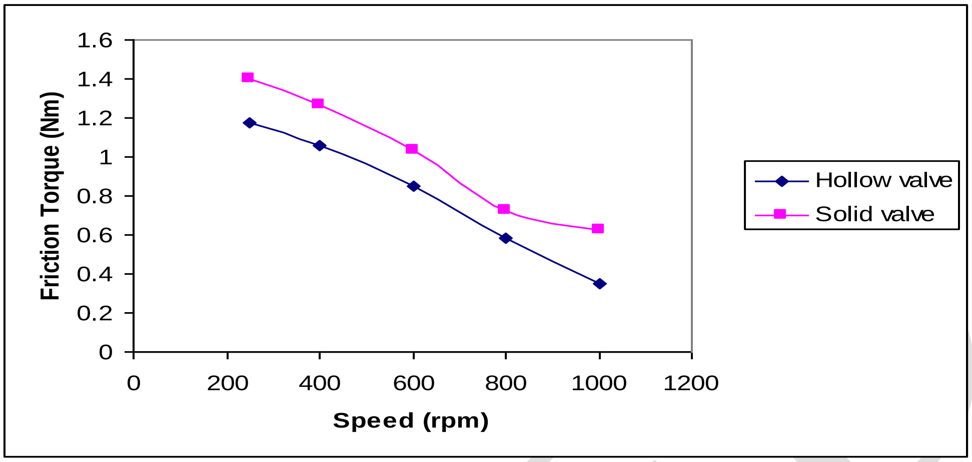

Figure 2 Comparison of friction torque for hollow and solid valve

Thus, considerable reduction in valve train friction can be achieved by using hollow valves.

2. FRICTION MODIFIERS

The film thickness variation between cam and follower indicates the boundary lubrication is dominant around the cam nose. The introduction of friction modifier additive such as molybdenum dithiocarbamate (MoDTC) is required to reduce boundary friction. MoDTC along with ZDTP forms the lower shear resistant surface films by chemical reactions, which reduces the friction. For lubricating oil (SAE 40W/20) friction modifier reduces limiting boundary friction coefficient from 0.12 to 0.08. Taking this into account in friction transition model, friction torque is calculated for push rod type valve train as shown in figure 3.

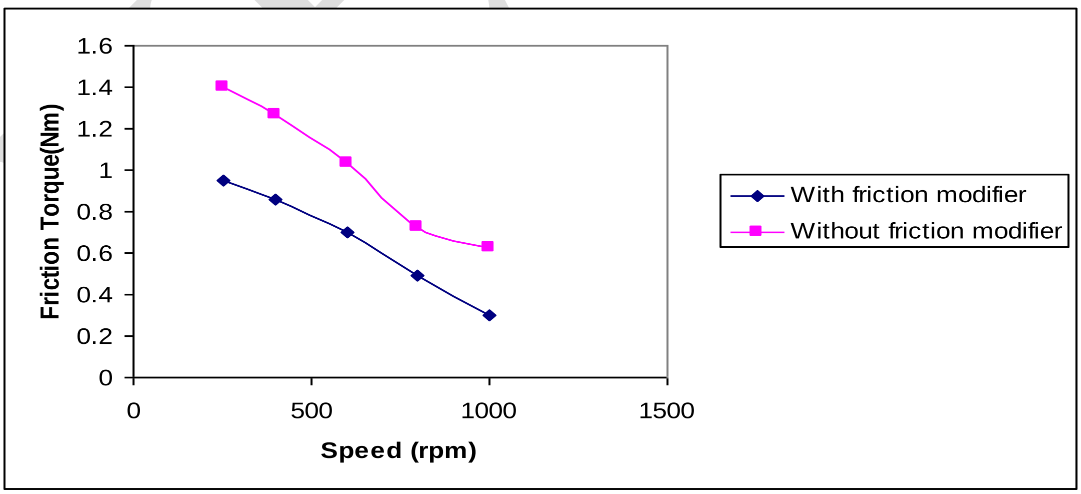

Figure 3 Friction torque with and without friction modifiers

The fig. 3 indicates a substantial decrease in frictional torque with the use of friction modifiers.

CONCLUSION

The reduction of inertia mass of valve train leads to reduction of force required by spring to maintain contact between the cam and follower thereby reducing friction forces. A hollow valve has been shown to reduce the inertia mass and thus contributes to the reduction in friction. The introduction of friction modifier additive such as molybdenum dithiocarbamate (MoDTC) significantly reduces the boundary friction.

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