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Analysis of Valve Mechanism – A Review

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ABSTRACT : *The main role of the valve train is to ensure the gases exchange process for all the engine speeds. The valve gear mechanism of an I.C. engine consists of those parts which actuate the inlet and exhaust valves at the required time with respect to the position of piston and crankshaft. The gases exchange process influences the engine good functioning, a kinematic and a dynamic analysis are required for the engine valve train. The vibratory and acoustic behavior of the internal combustion engine is a highly complex one. The engine speed is the most important parameter in valve train dynamics. A flexible multi-body model can be used investigate the dynamic behavior of a valve train by considering the interactions between valve train components i. e. the model includes a flexible camshaft, spring and rocker arm.*

Keywords – *Valve train, Internal combustion engine, Simulation, Kinematic analysis, Dynamic analysis*

I. INTRODUCTION

Internal combustion engine valves are precision engine components. The valve train system is one of the major parts of internal combustion engine, which controls the amount of air-fuel mixture to be drawn into the cylinder and exhaust gas to be discharged. The fresh charge (air - fuel mixture in Spark Ignition Engines and air alone in Compression Ignition Engines) is induced through inlet valves and the products of combustion get discharged to atmosphere through exhaust valves. This seals the working space inside the cylinder against the manifolds [1, 2, and 3]. So design of valve lift profiles and valve train components is most important for the engine performance, valve train durability, and NVH. Therefore valve train system should be optimally designed so as to avoid an abnormal valve movement, such as valve jumping or bounce up to the maximum engine speed. There are different types of valves used by the manufactures; some common types of valves being poppet valves, slide valves, rotary valves and sleeve valve. The basic nomenclature used for valves is as shown in Fig. 1.

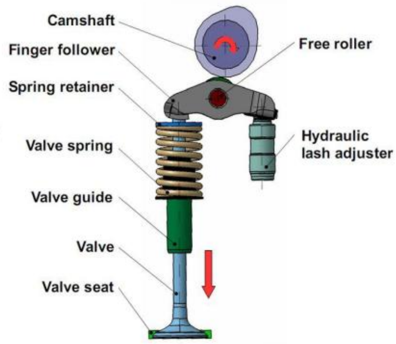

Fig.1. Engine valve mechanism

In the valve mechanism, the valve spring plays an important role in the system dynamics and its accurate modeling is required. A multi-body model makes it possible to study the dynamic behavior of the timing system, considering the elasticity of the bodies and evaluating the stress, strain and vibrational states of the components under different operating conditions in a more accurate way [1].

II. OBJECTIVES OF VALVE TRAIN

Valve train design and the valve timing directly affect the engine performance. The important objectives of valve train are;

Engine performance: The main requirements here are the exact timings (Valve opening and closing), a high volumetric flow (flat valve lift), and fast opening and in some cases a short overlap period. The usual considerations for design optimization are WOT (wide open throttle) performance characteristics for gasoline engines and full load smoke for diesel engines [4].

Durability: The limits for the design are given by Hertz pressure, the oil film thickness at cam/follower, velocity and force at the valve seat, prevention of contact loss and valve bouncing.

Vibration and Noise: Optimum solutions are achievable with high stiffness and high natural frequencies of the valve train. The impacts and the inertia forces should be minimized.

III. VALVE TRAIN SIMULATION

The development of simulation tools helps in valve train design [2]. The dynamic simulation of a valve train can be done using different software available in the market like, CATIA, PRO/E, Mat Lab, etc. A computer model is developed to study the dynamic behavior of a pushrod, tappet. For accurate simulation, the model had many degrees of freedom and will be decided based on requirements accuracy of simulation and convergence. The model is used to investigate following;

- The dynamic behavior of a valve train over operating speed range
- The harmful consequences of strongly exciting valve train resonances
- The minimization of valve train resonances.

In general, valve train resonances are excited by camshaft's lift profile. The aggressive motions will excite valve train resonances. Valve train resonances can either increase or decrease component loads, depending upon the resonance phase relationship with the valve train's non-resonant loadings. When resonant and non-resonant loadings are additive, higher contact stresses occur. When these two loads are out of phase with each other, the component separation can occur. During severe separation, each component acquires a different velocity leading to high impact loads.

IV. VALVE TRAIN ANALYSIS

Valve train analysis procedures are carried out in two stages kinematic and dynamic analysis. Kinematic analysis is used for design of a valve lift profile and find out static forces and Oil film characteristics, etc. Dynamic analysis is used to determine the dynamic movement of valve train component considering the effect of inertia and stiffness [3].

4.1 Analysis Model

A virtual model is used for the valve train analysis is developed by using various software's available in the market. This developed model contains the geometry of valve train system, mass, stiffness, and damping of each part. The model consists of several lumped masses. The different models for the analysis should be prepared according to the various valve train types such as direct acting, end pivot, center pivot type, and etc. [3].

4.2 Kinematic Analysis

The kinematic analysis is used to design a valve lift profile and calculate static forces, as the valve lift is the major factor to improve the engine performance. The kinematic analysis is to optimize the valve profile so as to maximize the area under the valve lift curve. Generally, the valve has to be opened and closed as quickly as possible in order to allow the maximum amount of charge to be drawn into the cylinders. However the area under the valve lift is limited by certain kinematic constraints, such as the maximum engine speed without abnormal valve movement, ability to manufacture, durability, and NVH. When a new valve lift profile is designed, for instance, we have to evaluate whether the kinematic guidelines are satisfied or not, such as maximum positive acceleration, maximum cam-follower contact stress, minimum radius of curvature and spring cover factor, etc. And then the valve lift should be repeatedly modified until the area below the valve lift is maximized. The manual kinematic optimization processes like this are very laborious and time-consuming jobs.

4.3 Dynamic Analysis

Dynamic analysis is a kind of multi-body dynamic analysis to predict the dynamic behavior considering stiffness and damping between the parts of valve train system. From the dynamic analysis, we can determine dynamic valve motion, dynamic forces between cam and follower, spring surge vibration. Besides, valve seating force, camshaft driving torque, camshaft bearing load, valve jump and bounce, and engine's dynamic limiting speed also can be calculated. The objective of dynamic analysis is to maximize dynamic limiting speed within constraint guidelines of dynamic analysis such as valve seating velocity, valve jump and bounce. In order to achieve the objectives, it's necessary to optimize the valve spring load and reduce the weight of each component. Sometimes even the valve lift should be redesigned.

The forces from dynamic analysis can be used as an input load for fatigue analysis, which predicts durability of the valve train components. Dynamic analysis is commonly divided into two steps, single cylinder analysis and multi-cylinder analysis for the purpose of analysis.

V. REVIEW OF RESULTS

At higher engine speeds the performance of the valve train becomes critical, especially related to the dynamic valve lift, velocity and acceleration. The displacement, velocity and acceleration curves for the valve are shown in Fig.2, Fig. 3 and Fig.4 at the rated speed and the over-speed [4, 5].

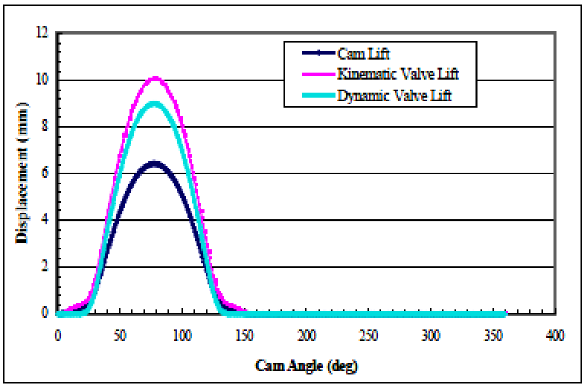

Fig.2.Displacement comparison [4]

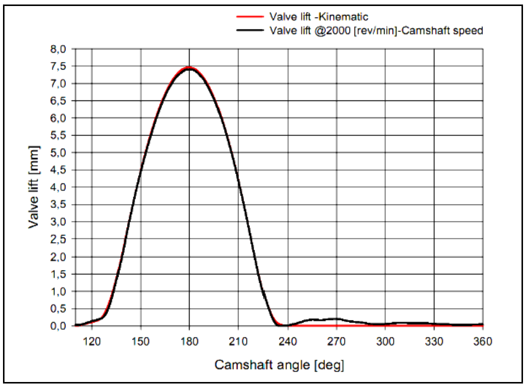

Fig.3. Displacement comparison [5]

From Fig.4 it is clear that the dynamic valve lift is comparatively lower than the kinematic lift. This is due to the flexural rigidity of the component and individual component damping. [4] This phenomenon has an adverse effect on the effective flow area and it leads to reduction in the volumetric efficiency of the engine. The breathing of the engine can be made effective by increasing the dynamic valve lift. Thus the dynamic valve lift can be increased by reduction in the energy losses in the valve train or by increasing the forces acting on the valve to the limit of durability.

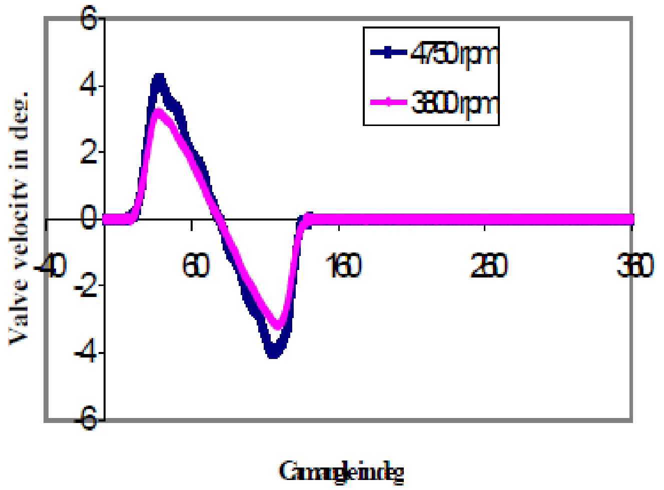

Fig.4. Valve velocity comparison. [4]

The Fig. 5 shows the valve acceleration comparison for two camshaft speeds 3800 rpm and 4750 rpm. And from Fig. 5 it is observed that the dynamic valve lift is comparatively lower than the kinematic lift. The Fig.6, shows the valve acceleration versus valve lift at 2000 rpm. All these figures are plotted by using the results obtained from the simulations of the developed model.

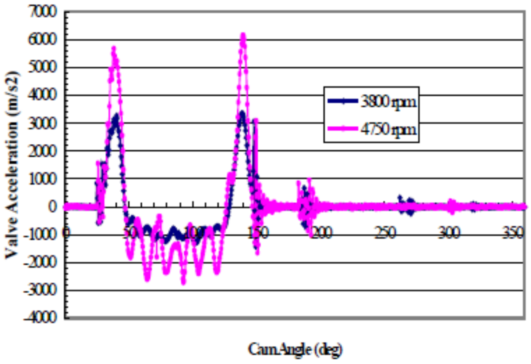

Fig.5.Valve acceleration comparison

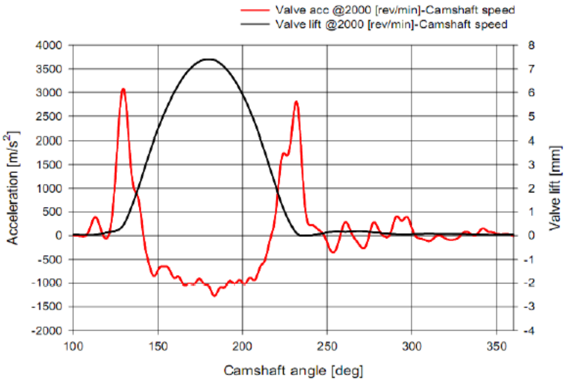

Fig.6. Valve acceleration versus Valve lift

VI. CONCLUSION

1. In this review it is observed that the dynamic model of valve train mechanism developed by using software can be used for the dynamic analysis of a valve train for the different camshaft speeds.
2. The valve design and the valve timing directly affect the engine performance. The simulation method is more effective way to depict the dynamical characteristics of valve train mechanism.
3. The dynamic analysis processes ensure the reliability of analysis results.
4. The dynamic behavior of the system is mainly induced by the cam profile with its specific displacements and acceleration. The rocker and valve dynamic behavior is correlated to the cam follower dynamic response.

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