

Development of a Cam Phaser System to Improve the Performance of a Small Engine

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ABSTRACT

In this work, a new mechanical cam phaser (MCP) system is developed. This MCP system is simple, reliable, and cost-effective, and also offers good control. Phasing of either intake, exhaust or both intake and exhaust cam can be achieved with this system. A prototype of the mechanical cam phaser has been tested on a motored rig to validate its dynamic characteristics. The system was tested onto a small two wheeler engine and this paper describes the newly developed MCP mechanism and its effects on the performance of a small two wheeler engine.

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INTRODUCTION

Achieving good engine performance and drivability in the entire operating range is a strong customer need in personal transport vehicles, especially two wheelers. Increase in the volumetric efficiency will greatly improve drivability. Valves control the flow of air in an engine, so valve timing is the most important parameter for improving the volumetric efficiency of an engine. Usually in small engines the valve timing is adjusted for power and hence low speed torque is compromised. The intake valve has to be retarded for power at high speeds to utilize the inertia of the incoming air effectively [1][2]. However, retarded intake valve timing will reduce engine breathing at low speeds due to charge back flow [2]. Currently all small engines use fixed valve timings and this results in a compromise in engine performance at some speeds. The best way to achieve good performance over the entire operating range is to manage the valve events so that they can be varied with speed. Thus with variable valve timing (VVT) optimal valve opening and closing times can be achieved at every engine speed [3]. A proper choice of valve timings can also provide a considerable reduction in pumping losses and also can be used to trap exhaust residuals for lowering NOx emissions [4]. Many types of variable valve timing methods have been listed in literature. Electromagnetic valve (EMV) control allows greater freedom for setting the valve timing. Such systems are not only costly but also need major changes in engine layout and design [5]. In addition to this EMV's are difficult to achieve

reliabilities equivalent to mechanical systems. Thus such systems cannot be adopted on cost sensitive small engines (< 250cc). Valve phasing mechanisms are generally used in four wheelers. However, very few mechanisms exist to efficiently phase the intake cam of small engines. Cost, complexity and size have to be low in the case of VVT systems for small two wheelers. So simple solutions are the best and are likely to enter into mass production. However, the challenges are in making VVT systems simple, cost effective, compact and also make them to work automatically without any external assistance. This paper deals with the development and evaluation of a simple intake valve phasing system for small two wheeler engines.

METHODOLOGY

Figure 1 shows the methodology that was followed. It started with the concept followed by detailed design. Experiments were conducted on base engine with different intake timings. Experimental data was used for tuning 1-D software to predict the best valve timing. Kinematics and motion of the mechanism were simulated using Pro-Engineer 3D modeling software. The Mechanical Cam Phaser (MCP) was then fabricated and assembled on a motored valve train test rig to validate its dynamic characteristics. Finally the system was incorporated on a small two wheeler engine and experiments were conducted to validate its performance.

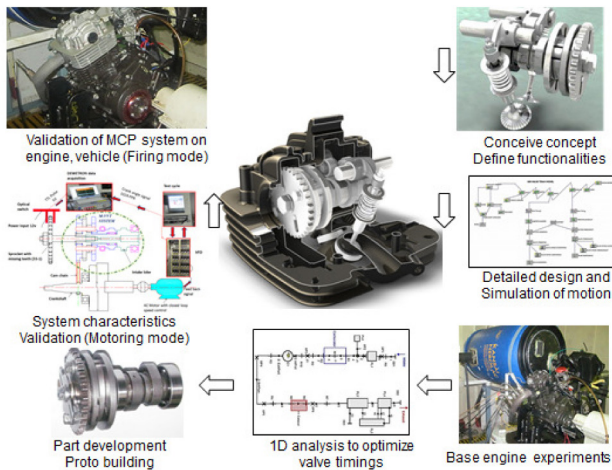


Fig. 1. Development methodology

THE DEVELOPED MCP SYSTEM AND ITS WORKING

In this design, phasing is achieved with respect to speed of camshaft based on principle of centrifugal force using a spring-mass combination. The basic elements of the developed MCP system are shown in Fig. 2 and 3. Cam chain drives the cam sprocket; a drive flange assembly shown in Fig. 3 is locked with D-slot on the Intake camshaft using a center bolt and rotates as a unit. Two straight slots/apertures are provided on the drive flange and a pair of pins located in flyweights drives (transmits torque to) the intake cam shaft which is to be phased relative to the crankshaft. The drive pins are also positioned variably in the sprocket and exhaust flange by a specific arc shaped aperture.

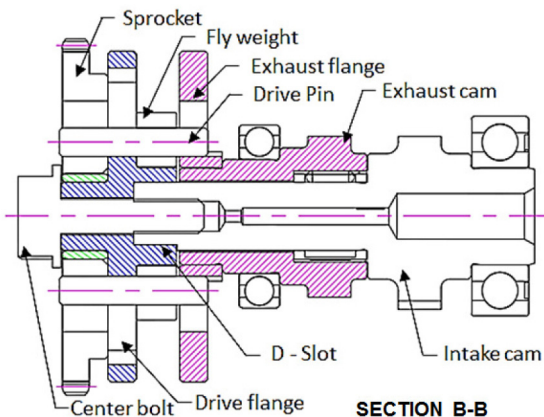


Fig. 2. MCP System construction

The drive pins are positioned variably in the sprocket and exhaust flange by a specific arc shaped aperture. The radial position of the drive pins decides the phasing value. Phasing is achieved with respect to speed of the camshaft controlled precisely by a combination of spring-mass (reactive centrifugal force) system. Fig. 3 shows sprocket and exhaust cam assembly details with a spacer in between. Exhaust flange is

press fitted with exhaust camshaft and is assembled to the sprocket by a pair of hexagonal head bolts; therefore, it has a fixed timing with the crankshaft.

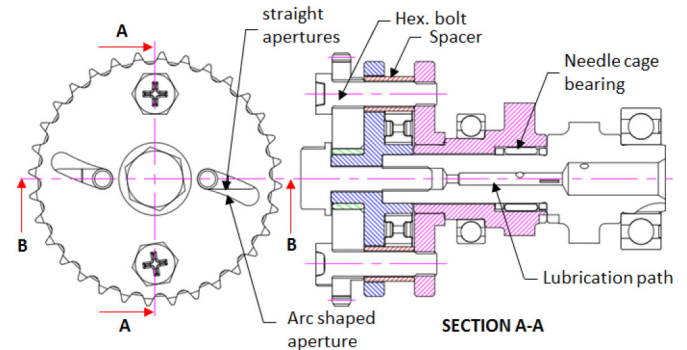


Fig. 3. MCP System construction

As the MCP system rotates the fly weights move radially out in a straight aperture based on the speed of the system. The radial motion of flyweights along with drive pin is converted to rotary motion of drive flange by aligning its straight aperture with arc shaped aperture in sprocket. Energy required to align the intake camshaft is significantly lower as the exhaust side (sprocket and exhaust flange assembly) is rigidly connected by timing drive system. In this manner, the mechanism varies the intake valve timing automatically based on speed without any external assistance. Fig. 4 shows MCP mechanism while operating at low engine speeds. Since the spring force is more than the centrifugal force below certain speeds (Low limit) the intake cam lobe is at its installed position i.e. valve closure timing is advanced.

Fig. 5 shows MCP mechanism while operating at higher engine speeds. Above certain speeds (High limit) the centrifugal force developed by fly weights are more than the spring force and the intake cam stays at its final position i.e. delays the closure of the intake valve by a cam angle θ as shown in Fig. 5. Between low limit and high limit the equilibrium of forces due to spring and fly weights (centrifugal forces) decides the radial position of pins. In the MCP system all parts are connected by mechanical links, constituting a forced drive.

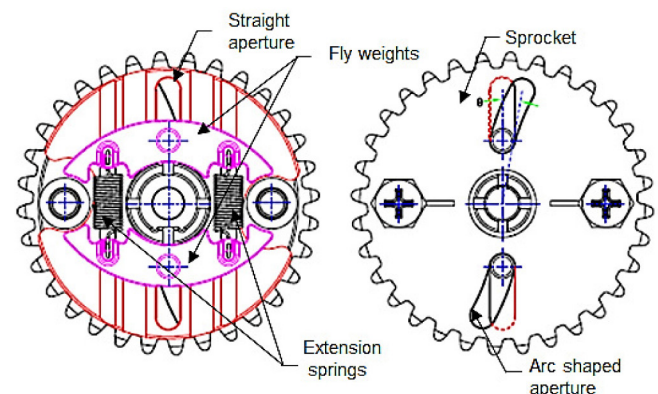


Fig. 4. Position of drive pins (Low speed range)

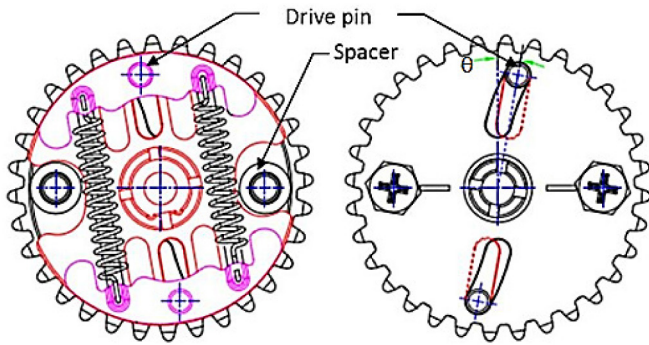


Fig. 5. Position of drive pins (High speed range)

The spring constant, spring preload, the mass of the flyweights, and the curved slot are carefully designed. During the base circle portion of the camshaft there is no load in the drive pins, centrifugal forces due to fly weights and spring forces together changes its radial position. The radial position of the pins decides the phasing between intake and exhaust cam. One of the critical factors for such a system to work against valve train load or torque is stability of the drive pin. Force due to intake drive torque should not change the position of pin, a combination of spring-mass force system (significant) and friction forces (less significant) ensures no random shifting of drive pin in radial position due to valve train loads. The relative motion is allowed only when there is a speed change (centrifugal force change). Fig. 6 shows variation of torque (intake and exhaust) acting on camshaft. So the profile of slot on the driving sprocket is designed such that pin transmits torque to the intake camshaft without slip. The instantaneous angle between straight slot and curved slot that can be used without slip is called as the limiting angle and it is a function of maximum intake camshaft drive torque. In order to ensure this maximum phasing angle θ is calculated from equation (1) which is 15 deg, however only phasing of 10 deg in camshaft is considered for design.

$$\theta = \cos^{-1} \frac{(\text{Spring forces} + \text{Friction forces})}{\text{Driving forces in sliding direction}}$$

(1)

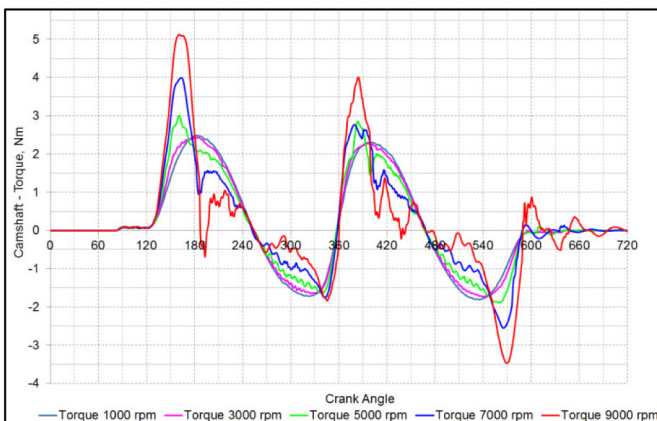


Fig. 6. Camshaft torque variation

In static analysis shown in Fig. 7 driving force acting on the pin in sliding direction, friction forces and spring forces are considered. During the intake cam phasing (when follower is on base circle) driving forces are minimum where centrifugal forces are dominant and are responsible for shifting.

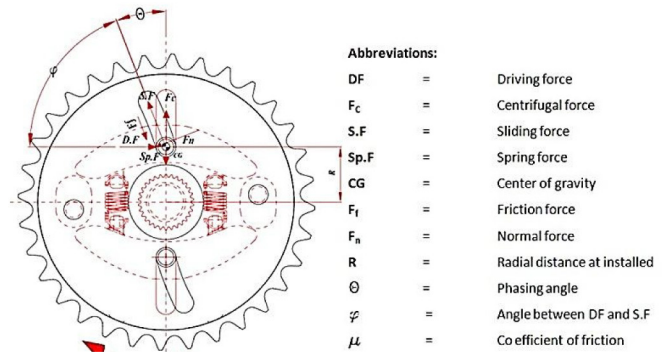


Fig. 7. Forces acting in MCP system

Centrifugal force balanced by spring forces at every engine speed. Eq. (2) (3) (4) gives centrifugal force, spring force and effect of friction force. Fig. 8 shows fly weights in the installed position and working position.

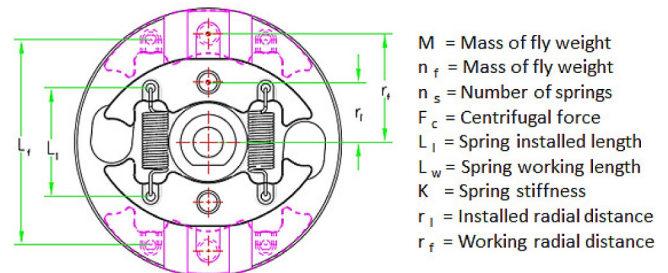


Fig. 8. Centrifugal force and its balance

$$F_c = m \times r \times \omega^2 \times n_f \quad (2)$$

$$F_{sp} = n_s (K \times ((L_w - L_i)) + \text{Installed deflection}) \quad (3)$$

$$(m(r_i + \delta_{new})\omega^2) - (F_n \times \mu) = (\delta_{installed}) + (K \times \delta_{new}) \quad (4)$$

Factors Effecting Degree of Phasing

However phasing characteristics can be changed to the requirement by selecting proper spring stiffness, spring installed load and fly weights. Here mass of fly weights, spring stiffness, clearances between sliding pairs are tuned to achieve required characteristics. Parametric analysis performed in order to study influence of various design factors. Parameters such as total moving fly masses (m), spring rate (K), spring pre-load (F pre-load) and friction force (F friction) have been analyzed. Fig. 9 shows influence of spring stiffness on phasing rate. Preload influences the speeds at which the phasing starts.