

Development of a Motorcycle Engine with a Three-dimensional Cam for Continuous Variable Valve Lift and Timing Mechanism

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ABSTRACT

From the viewpoint of protection of the global environment, reduction of CO₂ emissions are high-priority issues for vehicles, along with the demand for increased power performance. One of the more popular technological developments that can help to resolve such incompatible characteristics is the variable valve lift mechanism. Among them, the three-dimensional cam for continuous variable valve lift and timing mechanism has been developed as a technology applicable to motorcycles, because of its small, compact layout and capability of running under high speed engine conditions. The 3-D cam is provided with numerous cam profiles set in an orderly manner and forming a three dimensional map and at points making contact with a spherical roller tappet. An accelerator actuator slides the cam along the camshaft to continuously vary the power output from idling to maximum. Besides the above advantages, the 3-Dcam engine has the following positive characteristics: (1) By simply moving the position of the 3-D cam on the camshaft, the valve timing as well as the valve lift and event are changed simultaneously, thus removing the need of any Variable Valve Timing system. (2) It is possible to obtain the most suitable cam profile, including the cam ramp design, for each valve lift. To make the intake and exhaust valves simultaneously variable contributes to obtaining the optimum valve lifts and timings under all running conditions. (3) The lightweight inertia and the high stiffness of the valve trains can allow running under high speed engine conditions more than 10000rpm. (4) By adopting roller tappets any mechanical loss of valve trains is reduced in comparison with a conventional engine.

ordinary engine operation, both the valve lift and event are small and by closing the valve earlier to create the Miller cycle (expansion ratio > compression ratio), any pumping loss can be reduced, and fuel efficiency can be improved. Under high load conditions, the valve lift is high and the valve event is large, and the Otto cycle (expansion ratio = compression ratio), as found in conventional engines, is created. By setting a lift and event that correspond to the power output, it is possible to generate higher power output compared to conventional engines.

As one of the continuous variable valve lift mechanisms, the three dimensional cam engine for continuous variable valve lift and timing mechanism, as shown in Fig.1, has been developed. The 3-D cam engine has a very simple valve lift mechanism, consisting of only 3-D cams and spherical roller tappets, as shown in Fig.2. Therefore, compared to other mechanisms ⁽¹⁾⁻⁽³⁾, it has a lighter-weight valve train system with a smaller number of parts. The absence of any linkage mechanism gives high stiffness to the valve trains and allows running under high speed engine conditions. In addition, by simply sliding the 3-D map shaped cam not only the lift and event but also the valve timing is varied. Therefore, there is no need of any current hydraulic or electric Variable Valve Timing system, which responds late to valve lift changes. For this reason, non-throttling operation is possible at both steady and accelerating speeds. This report presents the structure of the 3-Dcam engine, the characteristics of engine performance and the results of valve lift and timing simulation analysis.

INTRODUCTION

As a technology to improve the fuel efficiency of gasoline engines, continuous variable valve lift mechanisms have recently been in the spotlight. The continuous variable valve lift mechanisms control power output from idling to maximum, by continuously varying the valve lift, instead of the conventional throttle valve. In the partial load area that is frequently used for idling and

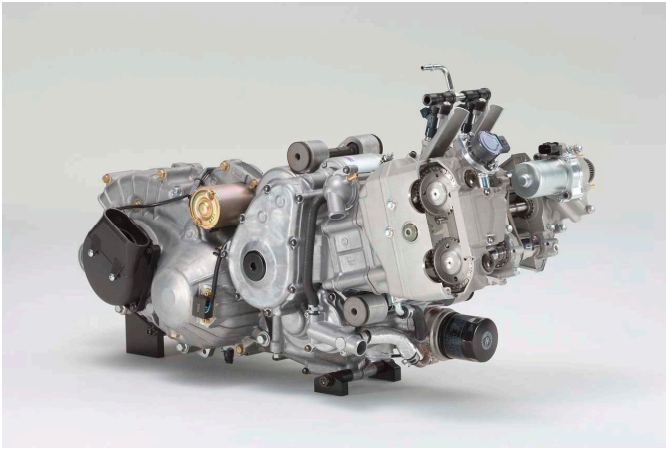


Fig.1 Engine feature (cross section engine model)

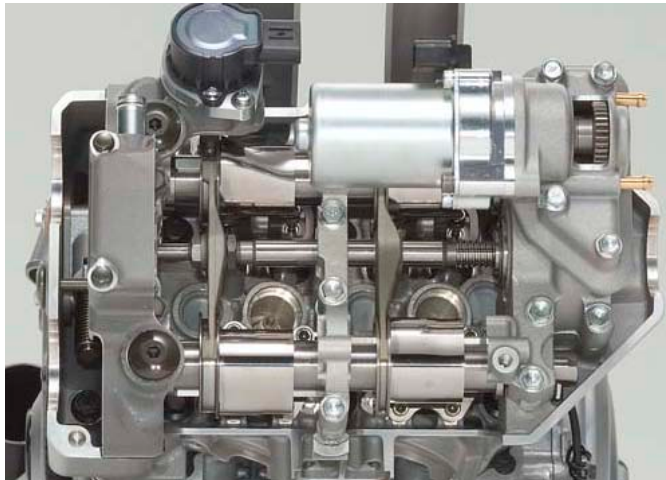
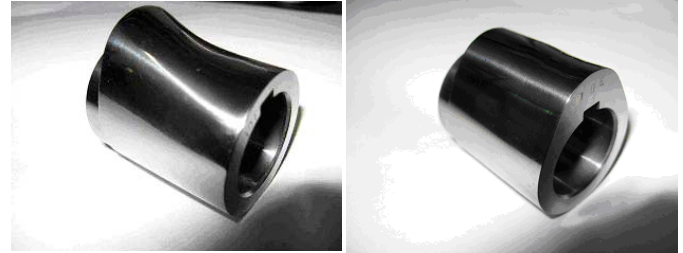


Fig.2 Valve train system

One of the characteristics of the 3-D cam is that it is possible to obtain the most suitable ramp design for each valve lift. The ramp design of the cam profile greatly affects the amount of damage to the valves and valve noise. Therefore it can be considered that this high degree of flexibility under these settings is advantageous for durability, noise, vibration and harshness.



(a) Intake

b) Exhaust

Fig.3 3-D cam lobe

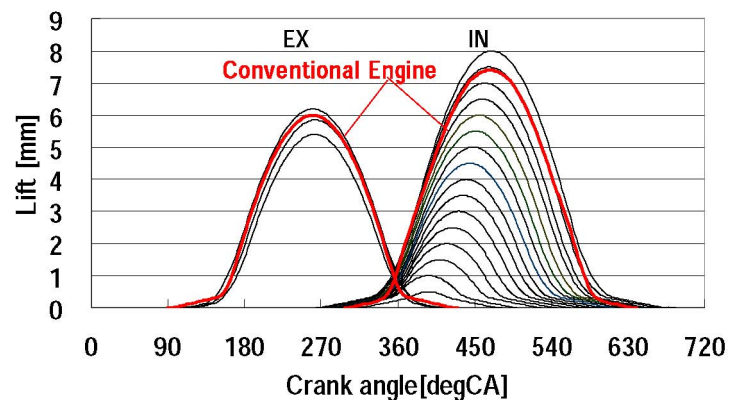


Fig.4 Valve lift curve

BASIC STRUCTURE OF THE 3-D CAM ENGINE

3-D CAM

The 3-D cam is made up of numerous two-dimensional cam profiles set in an orderly manner and forming a three dimensional map, as shown in Fig.3. While an intake cam has only a one-way inclination, the exhaust cam has a concave part on the cam surface to ensure the optimization of power output and fuel efficiency.

The cam and roller tappet make contact at points and the cam slides along the camshaft, allowing the valve lift, event and timing to be varied continuously. Fig.4 shows typical valve lift curves for the 3-D cam engine. A variable intake and exhaust contribute to obtaining an optimum valve lift characteristic for each power output.

The variable range of the intake valve lift of the present test engine is between 0.5mm and 8.0mm, however, it is possible to set a wider range, giving a higher degree of flexibility for the lift setting.

SPHERICAL ROLLER TAPPET

Fig.5 shows the spherical roller tappets that make contact with the 3-D cams at points. A balance-style arm is attached to a self-aligning ball or needle roller bearing with a spherical outer ring and the arm pushes down the two valves. The section shape of the outer ring of the tappet is designed in accordance with the surface shape of the cam model.

A tappet moves up and down along the tappet guide shown in Fig.6. Because of the inclination of the 3-D cam, the tappet receives a component force in the direction of thrust. However, the thrust component force is received by the tappet guide. Therefore, the bearing section receives only a radial load.



(a) Intake tappet



(b) Exhaust tappet

Fig.5 Spherical roller tappets



(a) Trapezoidal screw thread



(b) Ball screw type

Fig.7 Spherical Roller Tappets

ACCELERATOR MOTOR

A DC motor (80W) is adopted as for controlling the cam position. The property for motor output was set based on the response to the throttle in combination with the reduction gear ratio. The cam stroke under fully open and fully closed conditions is approximately 30mm, and its speed of upward movement is about 0.25sec.

ADJUSTMENT MECHANISM

To adjust the tappet clearance, an adjustment screw attached to both arm ends of the tappet adjusts the gap between the cam and tappet.

With regard to the alignment of the valve lift between cylinders, by using an adjustment nut attached to the accelerator shaft and making fine adjustments to the position of the No. 2 accelerator fork in the thrust direction, the position of the cam is adjusted and the No. 1 and 2 are set to give the same lift while the valve lift is actually being measured. With this technique the difference of valve lift between cylinders is adjusted to approximately $\pm 0.01\text{mm}$.

DURABILITY OF PARTS

CAM LOBE

The 3-D cams make contacts with the spherical roller tappets at points, therefore, the stress is generated higher than on conventional cams. To avoid excessive surface pressure between the cam and tappet, the maximum acceleration of the cam profile is lowered for reducing the load due to inertial force. However, simply lowering the maximum acceleration gives rise to the risk that the valve lift area may decrease resulting in a reduction of the power output. As a measure to counter this problem, a constant acceleration curve was adopted to minimize the reduction of the valve lift area in the same lift, as shown in Fig.8.

In opposition to acceleration, around the cam nose, the spring reaction force due to valve lift becomes greater, because the lower the running, the closer to the static conditions. The example of Hertz contact force at each engine speed is shown in Fig.9.

At the low lift side, the radius of the cam nose is small, but the spring reaction force is also low. On the high lift side, the spring reaction force is high, but the

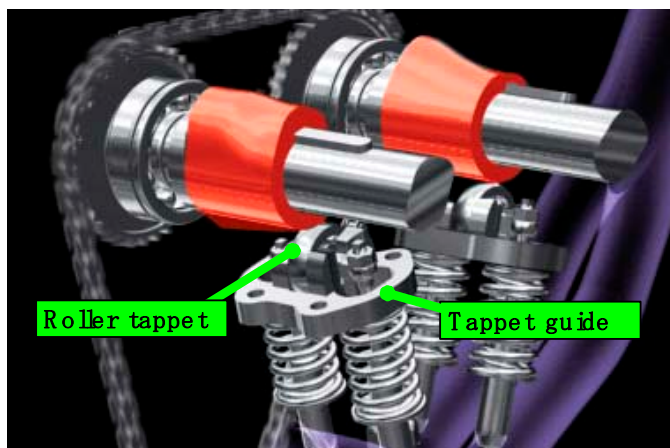


Fig.6 Tappet guide

ACCELERATOR SHAFT

An accelerator shaft actuator converts the rotation of an accelerator motor to a movement in a thrust direction and via an accelerator fork, moves the cam along the camshaft.

For the accelerator shaft mechanism, two types of actuators – a trapezoidal screw thread type and a ball screw type, as shown in Fig.7 – were evaluated. The trapezoidal screw thread type has the great tolerance against the thrust load from the cam, and due to its self-lock mechanism, there is almost no need of a holding current. The ball screw type demonstrates good response to the throttle, but needs a holding current.

At present, in consideration of its application to a two-wheeled vehicle, development is being carried out with the ball screw type because of its responsiveness.