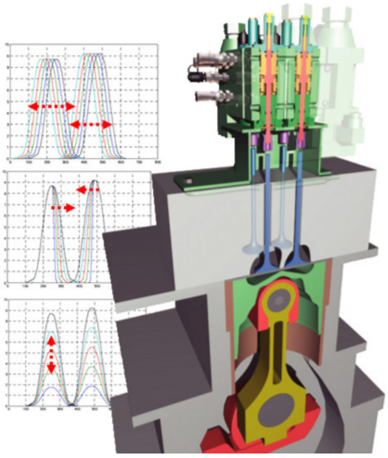
Engine Valve Control System - High-speed, Highly-accurate Valve Mechanism Contributes to Development of Advanced Engine -



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The Engine Valve Control system (EVC) with a high-speed hydraulic actuator is a test device which allows a variable valve lift by driving the valve with a hydraulic actuator instead of a cam mechanism. The system offers high flexibility and high-speed operability. The EVC system structure and recent modifications are presented here in this report. The system has been demonstrated to be a highly effective tool for engine development and combustion study through introduction to applicable engines and production experiences.

1. Foreword

Recently, exhaust gas from automobiles is required to be cleaner and to result in reduced carbon dioxide emissions by improving fuel consumption. The energy-saving competition, especially among gasoline cars including hybrid models, is escalating, and cost reduction and shorter lead times in engine development are urgent needs of automobile companies.

Furthermore, in advanced combustion studies such as the Homogeneous Charge Compression Ignition (HCCI) and Miller cycle engine, the desired change of cam profile as well as the valve open/close timing, lift, working angle and inlet-exhaust valve overlap are required.

The variable valve mechanism has been attracting attention as an engine testing device in the trend noted above, and a test device with a high degree of freedom and operability under high-speed operation is required. The valve drive with an electromagnetic or hydraulic actuator allows the variable valve mechanism a high degree of freedom. The electromagnetic actuator has a good response, but its position control capability is low with poor output power. The actuator is applicable only to the ON/OFF control, but inadequate for the accurate repetition of a valve lift pattern. Contrarily, the hydraulic actuator shows good controllability with high output, but it has difficulty under high speed operation with inferior response. Mitsubishi Heavy Industries, Ltd. (MHI) has developed a small, high-response hydraulic servo valve and actuator, and created the engine valve control system (EVC) to realize the full degree of freedom and high-speed applicable variable valve with it.

EVC eliminates test cam production and re-arrangement of the mechanism, and allows significant reductions of cost and test period in engine development. In addition, the full degree of freedom and high-speed applicability allows the reduction of fuel consumption ratio and optimization of power output by the lift pattern in various engine specifications. Well-repeatable combustion data from various lift patterns in the advanced combustion study become available instantly.

In this report, the EVC system structure and recent modification examples are described, and the applicable engines and production/shipping results are introduced.

2. System Outline

Figure 1 shows the EVC system structure. The EVC consists of a hydraulic actuator/servo valve installed on the engine head, a hydraulic pump unit as the power source, sensors, a control device and other components. The valve open/close is done with the extension/retraction of an actuator, and the repetition of the required valve lift is available by controlling the actuator position. The actuator and valve are not directly connected to provide an adjustable clearance between them to absorb the thermal expansion, and this realizes an operating condition quite similar to that of a cam drive.

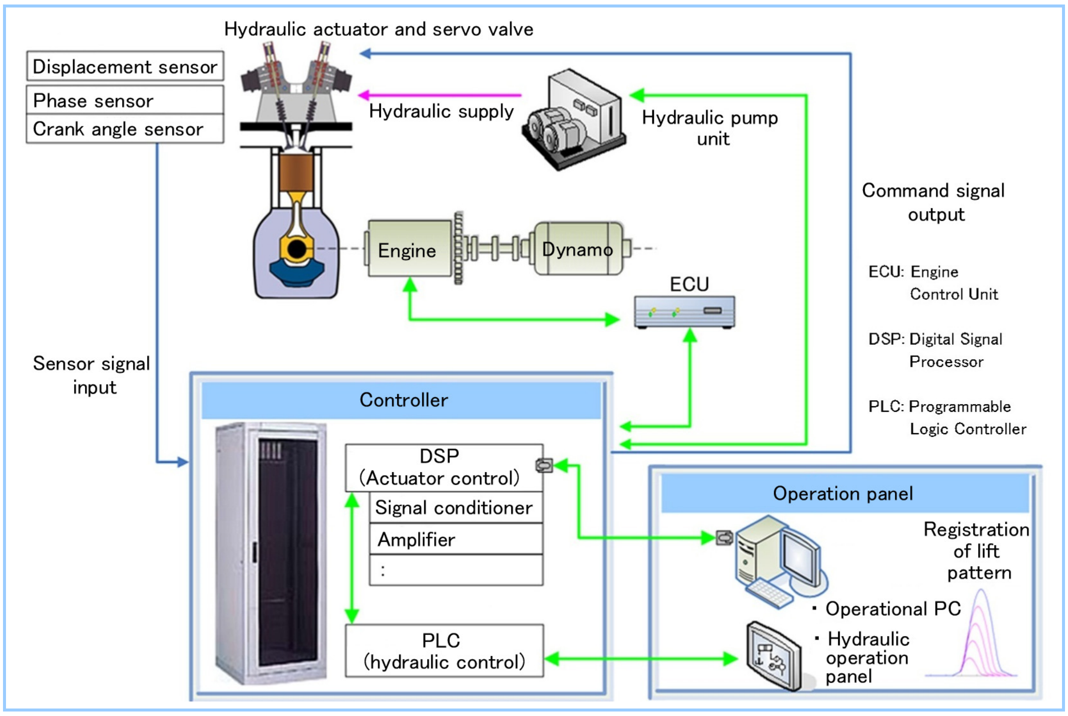


Figure 1 System structure

Figure 2 shows an example of four actuators installed on a single cylinder four valve engine. The actuator is individually installed/controlled, and integrated as a module. The actuator is available to install any engine independent of the number of cylinders and valves. The actuator is installed on the engine with a dedicated adapter. One actuator set can be applicable to multiple engines by changing the adapter to enhance the cost-effectiveness with increased utilization opportunities. In addition, one actuator can drive two valves with a bridge to meet the need of minimum initial cost.

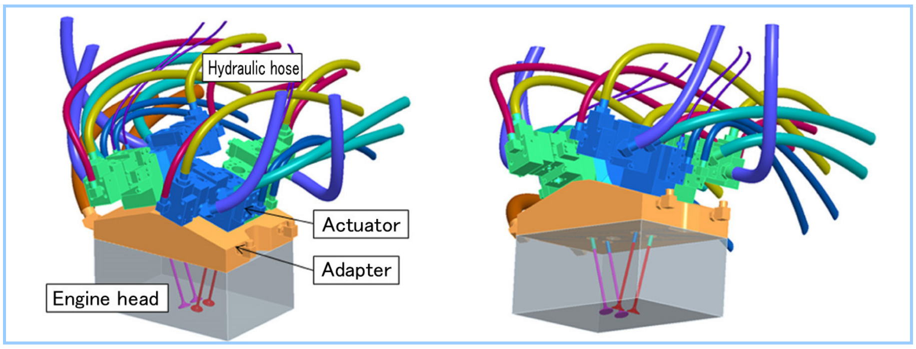


Figure 2 Head installation example

A variable valve testing device such as the EVC is required to be operable at a high speed, and have an accurate repeatability of the lift pattern. Our EVC features an accurate repeatability of valve lift in high-speed operation. One of the important elements to dominate the response at a high-speed is the servo valve. The servo valve in the EVC adopts a special proprietary structure with a response of 500Hz, a flow rate of 100L/min or more and size that allows installation in a small engine.

The sensor and control device consists of the crank angle sensor, actuator position sensor, real time control Digital Signal Processor (DSP) and other components. The actuator position is real-time controlled to attain the target valve lift referring the current crank angle. The control software was co-developed with Ono Sokki. The software has the function of phase retard compensation and self-studying, in addition to feed-back control, and contributes to the high response and repeatability of the EVC together with the high response servo valve noted above. The system allows also the transient mode operation, and the speed and load are changeable during engine operation.

Lift pattern switching can carried out by CAN communication to ECU in addition to the manual setting by operating a PC. In the manual setting, the valve lift, timing, working angle, and other parameters can be changed individually based on the registered pattern, in addition to the selection of a registered pattern. Sequential pattern change without stopping engine operation drastically increases the test efficiency compared with testing using a cam drive. Moreover, continuous testing under the same environment contributes the higher reliability of test data.

In operation using communication from the ECU, a lift pattern change in each single cycle is available. With this function, mapping referring to the engine conditions, such as the cylinder pressure and load, can be carried out using the ECU. This will provide the optimal pattern operation which is needed at all times, and is expected to contribute to advanced research and development.

3. Example of Lift Repetition Capability

The two main features of our EVC are its good lift repetition capability under high-speed operation and its high flexibility of lift change. Recently, we were able to obtain further improvement of the repeatability under high-speed operation, and less accuracy degradation at lift pattern switching by improving the high-response servo valve and control system. The case is described as below.

First, the servo valve was improved for better repeatability under high-speed operation, and we succeeded in increasing the flow rate without enlarging the size. As the flow rate of the servo valve was in proportion to the actuator speed, and an actuator drive with a high speed was made, attaining the maximum velocity of 6 m/sec. **Figure 3** shows an example of the lift pattern repeatability at a speed of 6000 rpm. The figure indicates the overwriting of 100 cycle responses. The lift pattern is repeated with high accuracy, showing small cyclic response deviation and superior repetition accuracy.

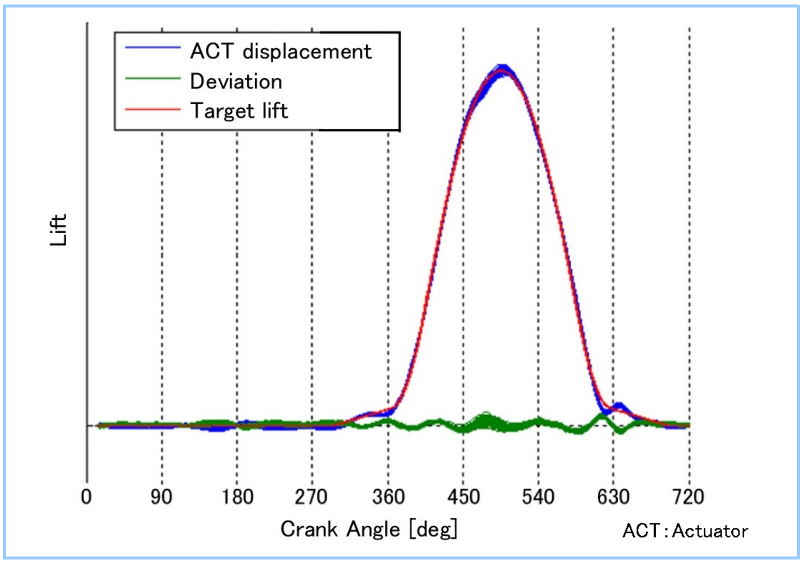


Figure 3 Example of lift pattern repeatability example at 6000 rpm

Furthermore, the accuracy at lift pattern switching was improved with a new control approach. In the EVC operation, on the occasion of communication with the ECU as noted above, lift pattern switching frequently occurs. Accordingly, it is desirable to minimize the transient deviations that appear on switching.

Figure 4 shows the accuracy before and after switching when the lift pattern is significantly changed. There is little difference in accuracy degradation in transient response, and the driving keeps a good accuracy immediately after switching is shown.

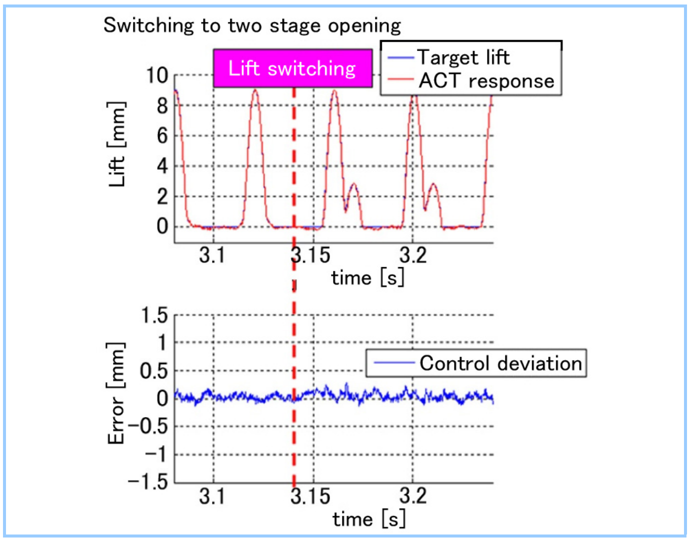
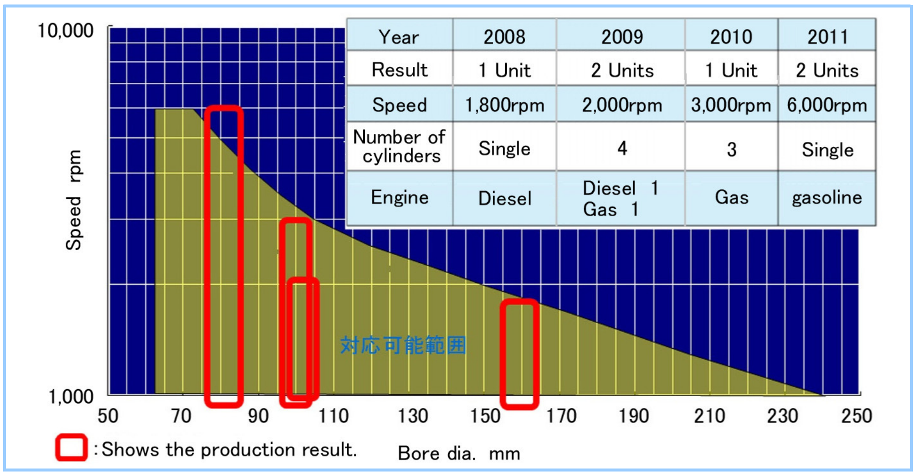


Figure 4 Accuracy before and after switching

4. Applicable Engine and Production Result

Figure 5 shows an engine to which the EVC can be applied. The EVC can be applicable to engine types ranging from large engines that require a large driving force to small engines that require a high response. We also have experience in production for various type engines, and we were able to obtain favorable comments from users such as “the optimization of the fuel consumption ratio and output power could be attained by the lift pattern change for every engine specification” and “the lead time for cam production and replacement was shortened.”

We also conducted an accelerated rig test of 124 million-cycle endurance of the hydraulic servo valve and actuator unit. The results showed that the accuracy was the same as that of a new unit, and the hydraulic servo valve and actuator were free from defects such as external oil leaks. The test period of this cycle test required about two years, and the test cycle number corresponds to approximately 8250 times of 10 minute, 3000 rpm tests. We believe that sufficient durability was verified.



Year	2008	2009	2010	2011
Result	1 Unit	2 Units	1 Unit	2 Units
Speed	1,800rpm	2,000rpm	3,000rpm	6,000rpm
Number of cylinders	Single	4	3	Single
Engine	Diesel	Diesel 1 Gas 1	Gas	gasoline

Figure 5 Engine with EVC

5. Further Improvements

By collecting and investigating user needs, we will provide test devices that are easy to handle, and allow the reduction of research and development time for advanced engines for the future. Moreover, we will investigate and improve the high-response servo valve developed in the EVC work in consideration of mass production and availability, in order to supply the valve for development jobs other than the EVC.