Stuck Valve Diagnosis for IC Engines Employing VVL Systems

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Abstract — **The increasing global concern for environmental conservation has led to stringent emission standards and a need for reducing fuel consumption. The automotive industry is thus always in search of technological solutions for reduced emissions and improved fuel economy. The variable valve lift system meets these requirements by providing control over the engine valve lift profiles. Obtaining the desired efficiency and emission standards, with an engine employing the variable valve lift, depends on the fault-free functioning of the valves. The introduction of electronic control in the automotive sector has made it convenient for vehicle manufacturers to maintain and provide highly efficient vehicles. This paper focuses on the stuck valve diagnosis of an IC engine with VVL system, governed by an engine management ECU. The various variable valve actuation methods are discussed. The diagnosis of stuck valves for an electro-hydraulic VVL system is validated in this research, by implementing the function on an engine control unit (ECU), and the simulation results for the same are provided.**

Index Terms— **VVA, electro-hydraulic valve, stuck valve, diagnostic, ECU, IC engine, VVL, VVT**

I. INTRODUCTION

The increasing levels of pollution and concerns of energy usage have led to research and production of electric vehicles. However, IC engines continue to be the dominant source of power for vehicles due to their affordability and robustness. It is thus necessary to utilize advancements in technology to meet the stringent requirements of reduced emissions and improved efficiencies. Variable valve actuation system is one such technology that helps improve engine efficiency while reducing emissions.

In conventional engines, the in-cylinder air flow is controlled by the rotation of the camshaft through a mechanical actuation and a throttle. This results in wastage of energy and a non-optimal metering of the air mass trapped in the cylinders according to the rapid changes of the driving conditions. Variable valve actuation (VVA) systems vary the timing, duration, and lift of the engine valve to provide improved engine efficiency while meeting emission standards. The variable valve timing (VVT) is a powertrain technology that allows control of transient phases for opening/closing of the intake valves. Whereas, variable valve lift (VVL) is a technology that varies the height to which an engine valve opens. VVA systems combine the VVT and VVL technologies. It can add functionalities such as in-cylinder charge motion control, improved combustion, improved stability, selective cylinder deactivation, exhaust gas recirculation, improved low-end torque, and a good volumetric efficiency across the entire speed range, to an engine. It also reduces pumping losses. Over the years many different VVA methods have been proposed and implemented. Some of these have been discussed in section II of this paper. These systems continue to be areas of interest for research as emission standards become more stringent.

In the EHVVA system, the dynamics of the engine's intake valves is decoupled from the cam profile by introducing a high-pressure oil volume and a fast-acting solenoid switching valve, which is controlled by an electronic engine control unit (ECU). The timings and lifts of the intake valves can be controlled independently, cylinder by cylinder and stroke by stroke, by acting on the solenoid valve. This possibility involves several actuation strategies to improve the performance in terms of fuel consumption, emissions and available power.

The main contribution of this paper is the diagnosis of stuck valves in engines employing VVA systems. It is organized as follows. Section II discusses the various

VVA systems and their benefits. Section III discusses the stuck diagnosis function and its dependence on profile tracking. Section IV gives the simulation results for the diagnostic function. Section V summarizes the paper.

II. VARIABLE VALVE ACTUATION SYSTEMS

The four basic control objectives for variable valve actuation systems are - valve lift control, valve timing control, profile area control, and soft-seating. The leading VVA technologies include the electro-pneumatic VVA (EPVVA), electro-hydraulic VVA (EHVVA), and electromagnetic VVA (EMVVA).

The electromagnetic variable valve actuation system uses electromagnetically controlled valves, which can operate optimally at all engine speeds, torque levels, and temperatures. These systems employ a hybrid of two methods – commanded holding and commanded acceleration, which are complementary [1]. The commanded holding method uses stored mechanical potential energy converted to kinetic energy for transition of valves and then stores the kinetic energy as mechanical potential energy to hold the valve in position until the next transition is desired.

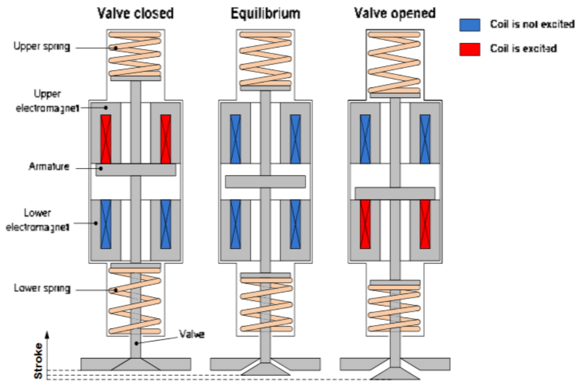

Fig 1 Principle of operation of EMVVA as in [2]

An electro-pneumatic VVA system actuates a piston-cylinder arrangement using air-pressure, which in turn actuates the poppet valves. Control valves (spool valves) are used to regulate movement of pressurized air in and out of the piston-cylinder arrangement. The spool valves are controlled by a solenoid. In order to reduce the energy consumption, EPVVA uses a hydraulic latch, allowing the actuator to extract the full expansion work out of the air that is drawn into the cylinder.

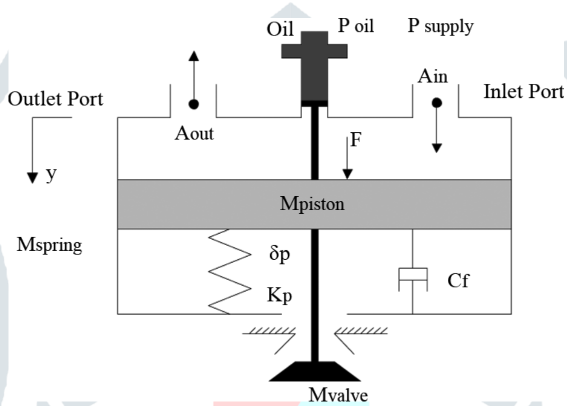

Fig. 2 EPVVA piston model as in [4]

The EPVVA consists of two control solenoids, an actuator cylinder, two port valves, two spool valves, an actuator piston, and a hydraulic latch-damper system [4]. Fig 2 shows the piston model for an EPVVA system. The cylinder can be single or double acting. In single acting cylinder, the valve is opened using pressurized air and is closed using a return spring. Whereas, in double acting cylinder, the valve is opened and closed using pressurized air. To open the valve, the upper chamber of the cylinder is allowed to be filled by the pressurized air, while the lower chamber is exposed to the atmosphere [5]. The difference in pressure across the pneumatic piston, moves the poppet valve downwards. The control valves are then closed to hold the valves in the desired position. To close the valve in a double acting cylinder, the air and oil chambers are depressurized and the control valves are opened.

The EHVVA system consists of an electro-hydraulic actuator, which is driven by a camshaft, with integrated fast-switching hydraulic valves. The EHVVA systems use a defined volume of oil, controlled by solenoid driven valves, to change the valve lift height and timing as desired. The position of the cylinder head in engines employing EHVVA can be chosen freely since the valves and cam are connected by a hydraulic interface [6].

III. STUCK DIAGNOSIS FOR EHVVA SYSTEMS

The solenoid valves are of central importance for controlling the EHVVA system as they are the control elements of the engine valves. The valve control module software individually controls the solenoid valves. The software stored in the engine management ECU is used to implement the requested lift modes with defined angles for opening and closing of the engine valves. To find the correct timing and actuation points, the software considers various factors that affect the system behavior [7].

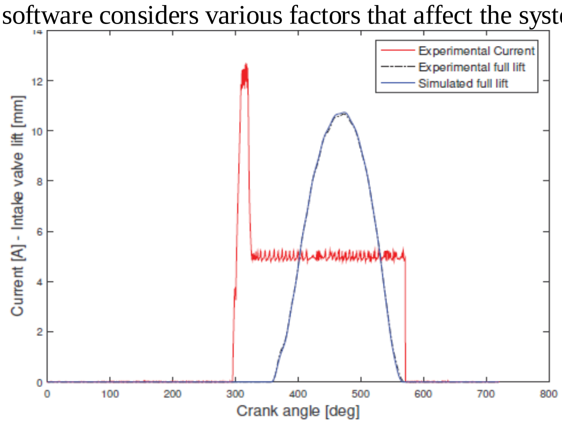

Fig 3 Current profile and lift curve for full-lift [10]

The detectability of the current profiles over the complete temperature range poses an additional challenge in EHVVA systems. Hence, profile tracking controllers are needed to obtain required engine performance. Various controllers for profile tracking have been proposed in the past [8] [9]. Fig. 3 shows the current profile for the full lift of the solenoid valves [10]. Based on the operating conditions, the current curve obtained, for each cylinder, needs to be adjusted and monitored depending. A stuck valve produces distortion of this profile. A distortion in the profile (Fig 3) of the transition region current indicates that the valve is stuck in open position or stuck in the middle of a lift. A distortion in the tail-current indicates that the valve is stuck in closed position. A good profile tracking controller could detect any such distortions in the profile. A fault flag is raised, based on inputs from the monitoring function, to indicate existence of a temporary fault. This fault is then monitored to confirm if the fault is permanent, in which case, it can be reported.

The fault diagnosis function discussed in this paper, consists of a diagnostic counter which checks the temporary fault flag for occurrence of fault and its healing. If the fault is permanent, it is reported by setting an error bit. This leads to the malfunction indication lamp (MIL) of the vehicle being lit. The recorded fault can be read by service station professionals and the valves can be fixed. Fig 4 describes the diagnostic counter.

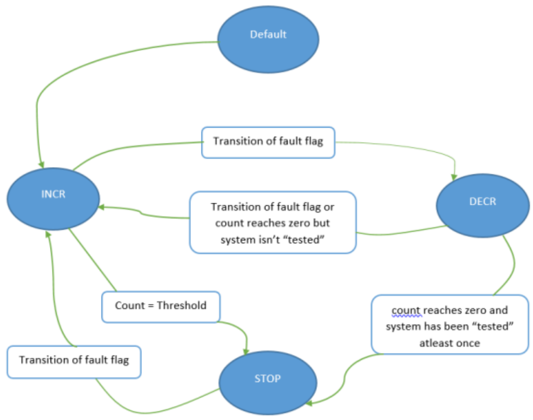

Fig 4 Diagnostic counter

The counter described above is used to monitor the faults. When the electrical readings are valid, and the system is active, the counter counts up. If the drive cycle if fault-free, the system is reported to be "tested", after the counter reaches a test threshold. If the fault flag is raised, the counter counts up after reset, until a predetermined fault threshold. This confirms the fault to be permanent and it is then recorded in the fault memory as a code. In case of a temporary fault, the counter counts down when the fault flag goes low, until zero. If the count reaches zero, the fault is considered healed, and it need not be recorded.

IV. SIMULATION RESULTS

The diagnostic function was designed on a model-based development software and its operating frequency was kept at 10ms, which is the fastest operating frequency supported by the ECU. The simulation results for the implemented function are analyzed in this section.

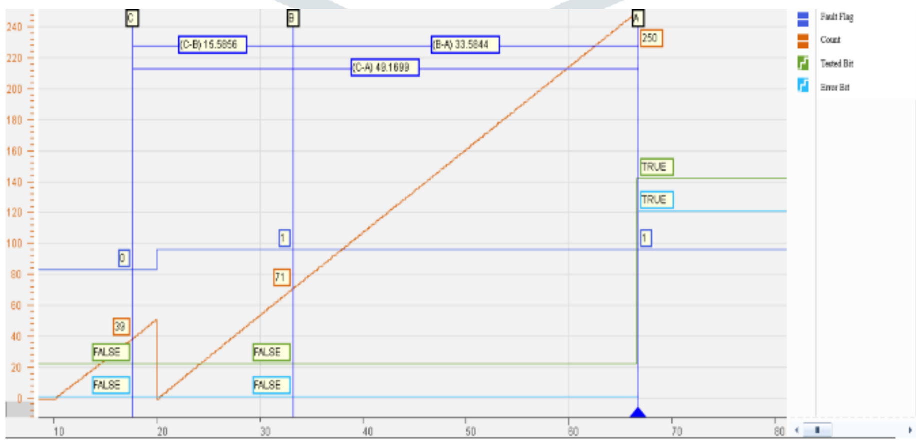

Fig 5 Fault confirmed to be permanent

Fig 5 shows the simulation result for when a fault occurs and is confirmed to be permanent. The fault occurs at 20s. At this point, the counter resets and starts counting up again. It counts up to the fault threshold, which can be decided by the OEMs. Here, the threshold is kept at 250. Once the count reaches 250, the fault is confirmed and the tested bit and error bit are set to TRUE.

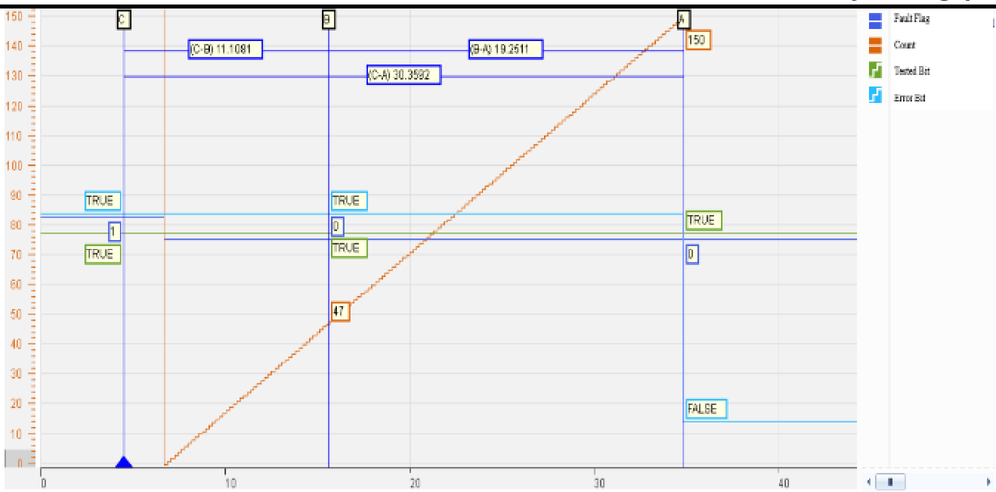

Fig 6 Fault healing confirmed

Fig 6 shows the simulation result for when a fault that was earlier confirmed as permanent and reported, heals. In this scenario, the counter is reset, and counts up. If the count reaches a pre-determined healing threshold (150 here), the error bit is pulled low to indicate that the fault is healed. If instead, a fault occurs again and interrupts the healing, the counter would count down.

V. CONCLUSION

This paper discusses the existing variable valve actuation technologies, the various methods of variable valve actuation and how these systems operate. These systems help improve the engine's performance and also helps decrease emissions to meet the increasingly stringent emission standards of the modern world. Hence, the need for diagnosing a stuck engine valve in such systems is discussed and a diagnostic function for detecting and reporting a stuck valve is designed and the simulation results for the same are presented. The implemented function detects a stuck valve based on the actuation current curve and reports a fault by turning on the Malfunction Indication Lamp (MIL) of the vehicle.

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