Research on Production Vehicle Evaluation Method of China VI OBD for Light-Duty Vehicles

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Abstract. With the gradual tightening of light-duty vehicle emission regulations, the fault diagnosis function of the on-board diagnostic (OBD) system is constantly improving and the monitoring items are also increasing. The production vehicle evaluation (PVE) test problem of latest OBD certification in the China VI emission regulations for light vehicles is studied. Firstly, the working principle and development process of OBD system is introduced. Secondly, the PVE testing regulations and testing process of OBD system is analyzed. It covers standardized verification (J1), monitoring requirement verification (J2) and in-use monitoring performance verification (J3). Finally, in order to improve the efficiency of PVE testing for such a large number of faults, a faults classification method based on fault type and function is proposed. OBD faults can be simplified into the six categories, which include circuit fault, tool performance fault, hardware performance fault, bus communication fault and exemption test fault. The simulation method of corresponding fault is introduced and analyzed as well.

1. Introduction

China has become the largest automotive producer and consumer in the world. At present, more and more cars have entered the homes of ordinary people. The cars are convenient for people to travel, enriching and improving people’s taste of life, but also bring environmental pollution problems [1, 2].

On-board diagnostics (OBD) system is designed to detect engine performance problems that cause emissions to rise with more precise methods. According to the requirements of GB18352.6-2016, as an important part of the company’s OBD system conformity of production (COP) self-inspection, when the vehicle is start of production (SOP), the company needs to submit the production vehicle evaluation (PVE) test reports and accept supervision and inspection [3].

This paper studies the PVE test problem of latest OBD certification in the China VI emission regulations for light vehicles. Firstly, the working principle and development process of OBD system is introduced. Secondly, the PVE testing regulations and testing process of OBD system is analyzed. Finally, a PVE test method of China VI OBD is proposed for light-duty vehicles.

2. OBD System Overview

2.1. The Working Principle of OBD System

The OBD system is an important part of the engine management system (EMS) and vehicle emission control system [4]. It monitors the operating status of the engine and the vehicle and the working
status of the exhaust aftertreatment system (EAS) at all times, and diagnoses their faults as well. When there is a fault such as excessive emissions or component damage, it may cause a significant increase in the emission of harmful substances from the vehicle. The engine electronic control unit (ECU) will record the fault information and related diagnostic trouble code (DTC). And it will also issue a warning through the malfunction indicator light (MIL) to inform the driver. The ECU accesses and processes fault information through a standard data connection port.

OBD has two purposes, where, one is to provide maintenance people with a monitor interface and the other is to determine emission standards by environmental protection departments. According to the DTC, the maintenance people can accurately obtain the feature and position of the fault, which creates favourable conditions for the fault to be repaired in time, avoids the extraordinary emissions caused by the faulty operating vehicle, and reduce the overall emission level of the in-use vehicle.

2.2. The Development Process of OBD System

The OBD system was firstly proposed by General Motors in 1981. The purpose of the OBD system is to effectively monitor the emissions of in-use vehicles by conducting on-line monitoring of vehicles and emissions-related subsystems and components. The Society of Automotive Engineers (SAE), the United States (US) Environmental Protection Agency (EPA) and the US California Air Resources Board (CARB) jointly proposed the OBD I standard in 1985. And it is implemented in 1988 in order to accelerate the maintenance speed of the fuel injection systems, improve maintenance quality and improve the vehicle exhaust emissions.

Due to lack of monitoring function, uniform standards and specifications in the OBD I standard, the US CARB began to propose the OBD II standard in 1989 and requested to implement it in 1996 [5].

Based on the OBD I standard, the OBD II standard adopts the unified data communication protocol and diagnostic mode, the unified digital loop connection (DLC) the uniformly DTC. And it also expands the diagnostic items of the OBD system. Where, the communication protocol mainly includes SAE J1850-VPW, SAE J1850-PWM, ISO 9141, ISO 14230, ISO15765-4. DLC is a 16-pin socket whose definition is based on SAE J1962 and ISO DIS 15031-3. DTC generally consists of one letter and four numbers according to SAE J2012. The European Union (EU) has implemented the EOBD standard since 2000, which is similar to the features and requirements of the OBD II standard.

In order to simplify the vehicle inspection process and save maintenance costs, the US CARB proposed the OBD III standard in 2004. The data transmission mode is changed from the original wire to the non-contact wireless. The wireless communication devices are used to report the real-time information and emissions of the vehicle to the environmental protection authority [6].

The relevant requirements of the OBD system in GB 18352.6-2016 “Limits and Measurement Methods for Emissions from Light-Duty Vehicles (China 6)” refer to the US CARB OBD II 2013 and 2015 draft. And the OBD threshold refers to Euro VI regulations. The change of the China VI OBD compared with the China V is mainly reflected in the significant reduction of emission pollutant limits and the increase of monitoring items. It shows that the China VI OBD system needs to quickly and accurately diagnose the faults of the emissions components and has a complete diagnostic function and usage frequency.

2.3. OBD System Testing

The OBD system testing mainly uses the OBD scanning tool to read the vehicle DTC to identify the vehicle operating state via the vehicle DLC. The PVE test is an additional requirement of OBD certification in the China VI emission regulation. It refers to the OBD compliance series test conducted on actual production vehicles after the vehicle SOP. The US has implemented the PVE test since 2002 and has undergone 17 years of development [7]. The PVE test requirements in the China VI emission regulation refer to the relevant requirements of the US PVE test.
3. PVE Test Requirements

3.1. PVE Test Process

The China VI emission regulation requires that each year the vehicle manufacturing enterprise should prepare a PVE test plan based on the OBD family, and divide it into three test groups in the OBD family including standardized verification (J1), monitoring requirement verification (J2), and in-use monitoring performance verification (J3). According to the grouping situation, select representative vehicle test and data statistics, and submit the PVE test plan and verification report to the regulatory authorities on a regular basis. The PVE test process is shown in figure 1.

PVE testing of domestic vehicles should be conducted domestically. Regarding imported vehicles, J1 and J2 tests can be conducted abroad but J3 tests must be conducted domestically. The production time based on the J1 and J2 test reports of domestic vehicles is based on the production time of the on-board list. The production time based on J1 and J2 test reports of the imported vehicles (including J1 and J2 tests in foreign countries) is based on the import time of the on-board list. The production time based on the J3 test shall be based on the domestic registration date of the first vehicle.

![Image of PVE test process diagram](image)

**Figure 1.** Production vehicle evaluation (PVE) test process.

3.2. Standardization Verification (J1)

The J1 test requires manufacturers to test vehicles to confirm that all vehicles meet the requirements for proper communication between the SAE J1978 Scan Tool and emissions related information and SAE J1699-3 (Vehicle Validation Testing).

The manufacturer shall select one of the representative vehicles and do the J1 test within two months after the vehicle SOP. And the manufacturer shall submit the J1 test report and recording files to the environmental protection authority within three months.

The J1 test is relatively simple. The J1 test content is fully embedded in the SAE J1699-3 software. The tester only needs to connect the vehicle DLC to the computer through an external device, start the SAE J1699-3 software test program and select the static test part. After that, the test program will run automatically. The J1 test process is shown in figure 2. The tester performs the operation as prompted, including prompting to turn on the electric fire switch, turn off the ignition switch, start the engine, make a fault, remove the fault, etc., until the software requirements are completed. All the test results
will be written to the log files in the form of ASCII code. Finally, the test report generated by the static test part of SAE J1699-3 and the accompanying explanatory documents are submitted to the environmental protection authority.

3.3. Monitoring Requirement Verification (J2)

The J2 test requires a comprehensive evaluation of the OBD system of the SOP vehicle. It is performed to verify all OBD DTCs of the vehicle. The OBD system should be able to detect faults, illuminate MIL and store the corresponding confirmed and permanent DTCs.

The manufacturer shall select one or more of the representative vehicles and do the J2 test within six months after the vehicle SOP. And the manufacturer shall submit the J2 test report and recording files to the environmental protection authority within six months.

The J2 test has the longest duration in the PVE test and the most complex test content. It is the most difficult test in the PVE test. The OBD DTCs for each illuminating MIL should be verified. The J2 test process for a single DTC is shown in figure 3.
Firstly, connect the relevant measurement equipment, clear the fault memory and implant the fault according to the fault simulation method of corresponding DTC. Then, start the vehicle to perform a driving cycle and wait for the pending DTC to appear. When the pending DTC appears, stop the engine and store the test file. Secondly, start the vehicle to perform the driving cycle again and wait for the confirmed DTC to appear and the MIL to illuminate. When the confirmed DTC appears and MIL illuminates, stop the engine and store the test file. Finally, clear the permanent DTC by natural or passive removal method. Where, the driving cycle refers to a complete process of powering on the vehicle, starting the engine, idling, driving, stalling, and sleeping. It consists of the engine starting, running and stopping states. And it also includes the process from the engine stop to the next engine start. Regarding the vehicle with engine start-stop control strategy, the manufacturer can define the driving cycle separately.

In addition, the China VI emission regulations explicitly require the using hardware methods for fault simulation and cannot use the modifying calibration methods for fault simulation.

3.4. In-Use Monitoring Performance Verification (J3)
The J3 test requires the manufacturer to collect the in-use performance ratio (IUPR) data of the vehicle representing the OBD family and submit it to the competent authority. The J3 test requires the IUPR data collection of at least 15 vehicles. The vehicle number could be less than 15 when the vehicle annual sales is less than 5,000. What is more, the vehicle shall run at least 6 months or its mileage should be greater than 15,000 km but less than 160,000 km. The monitoring items of IUPR tracking requirements must meet the minimum denominator requirements and the vehicle does not tamper or install the additional components. Therefore, the vehicle shall meet the conditions of normal maintenance, no abuse and no overhaul. The sampling method of the J3 test should use statistical methods to collect a large amount of OBD information of the vehicle to form a normal distribution chart of the IUPR data. The data of the distribution points are averaged in the IUPR normal distribution chart to ensure the representativeness of the J3 test data.

4. PVE Fault Simulation Method

4.1. Fault Classification
The main components and systems related to light-duty vehicle emission monitoring and OBD system functional monitoring include:

- Three-way catalyst (TWC);
- Fuel supply system and fuel injection system;
- Fuel evaporation (EVAP) emission control system and natural vacuum leak detection (NVLD) device;
- Secondary air system;
- Oxygen sensor;
- Exhaust gas recirculation (EGR) system;
- Positive crankcase ventilation (PCV) system;
- Engine cooling system;
- Cold start emission reduction control strategy;
- Variable valve timing (VVT) control system and variable valve lift (VVL) control system;
- Engine misfire rate;
- Gasoline particulate filter (GPF);
- Comprehensive components monitoring;
- Other components related to emission control.

In order to study the fault activation of the above OBD system related detection items, it is necessary to artificially simulate the related faults during the PVE test. When the OBD system satisfies the fault activation condition of the relevant DTC, it enters the effective fault monitoring condition.
When the OBD system satisfies the fault threshold condition of the relevant DTC, the DTC is reported and the MIL is illuminated to issue a warning.

With the continuous application and promotion of electronic control technology, EMS has become more and more complex and the software codes related to fault diagnosis have accounted for more than half of EMS software. In addition, the software codes related to fault diagnosis have exceeded 60% in some independent post-processing control system software. The OBD DTC number of a conventional energy four-cylinder light-duty vehicle is about 300. But the OBD DTC number of a new energy light-duty vehicle is 2 to 3 times that of the conventional vehicle, reaching about 800.

In order to improve the efficiency of PVE testing for such a large number of DTCs, a PVE test method of China VI OBD is proposed for light-duty vehicles, which aims to classify faults based on fault type and function, use similar fault simulation methods and tools, and simulate OBD faults for PVE testing.

OBD faults can be simplified into the following categories:

- Circuit fault;
- Reasonable fault;
- Tool performance fault;
- Hardware performance fault;
- Bus communication fault;
- Exemption test fault.

The PVE test requires that the manufacturer cannot simulate component failures by modifying the vehicle ECU software, but should perform fault simulation through hardware such as defective components. If the manufacturer can prove the environmental protection authority that the electronic fault simulation is equivalent to the hardware fault simulation, then the electronic faults simulation components can be used to simulate the faults during the PVE test.

4.2. Simulation Method of Circuit Faults

The circuit faults can generally be summarized as signal open circuit, signal short circuit to power supply, signal short circuit to ground, signals short circuit to each other, signal voltage too high, and signal voltage too low, etc. This faults simulation method can be summarized as signal disconnection, signal short circuit to power supply, signal short circuit to ground, signal short circuit to other signals, signal short circuit to high voltage signal, signal short circuit to low voltage signal. Where, the high voltage signal and the low voltage signal can be provided by an adjustable direct current (DC) regulated power supply.

Based on sensor and actuator signal characteristics, circuit faults can be subdivided into:

- sensor signal open circuit fault;
- sensor signal short circuit to ground fault;
- sensor signal short circuit to power supply fault;
- sensor signal voltage too low fault;
- sensor signal voltage too high fault;
- sensor signals short circuit to each other fault;
- actuator control signal open circuit fault;
- actuator control signal short circuit fault to ground;
- actuator control signal short circuit to power supply fault;
- actuator control signal voltage too low fault;
- actuator control signal voltage too high fault;
- actuator control signals short circuit to each other fault.
4.3. Simulation Method of Reasonable Faults
The reasonable fault phenomenon is that the value of the sensor signal or the actuator control signal is higher or lower than the threshold under the actual operating conditions of the vehicle, resulting in unreasonable signal fault.

The simulation method of reasonable fault is to connect the resistors in series or in parallel to simulate unreasonable fault phenomena such as signal value too high, too low or constant. Where, the sensor signal can be simulated via a decimal resistance box and the actuator control signal requires a high power resistor for reasonable fault simulation because of the large drive current.

4.4. Simulation Method of Tool Performance Faults
The tool performance fault phenomenon refers to the change of vehicle performance caused by the change of component performance under the actual operating conditions of the vehicle, so that the vehicle emissions also change.

The tool performance faults mainly involve Oxygen sensors, engine misfire rates and solenoid valve pulse width modulation (PWM) power stage driver. Oxygen sensor faults can be simulated by Oxygen sensor fault simulator such as IAV Primero. Engine misfire fault can be simulated by misfire generator, such as Global Electronic MisGen3 misfire generator. Solenoid valve PWM power stage driver fault can be simulated by PWM power stage driver, such as the Canadian PWM proportional valve driver.

4.5. Simulation Method of Hardware Performance Faults
The hardware performance fault phenomenon refers to the change of vehicle performance caused by the abnormal operation of the components under the actual operating conditions of the vehicle, so that the vehicle emissions also change, such as the electronic throttle stuck, the VVT valve moving slow, TWC aging and other phenomena.

The hardware performance faults cannot be simulated by fault simulation tools. Certain defective components are required for fault simulation. The required hardware mainly includes electronic throttle valve, hot film air mass meter (HFM), VVT valve, TWC, and other vehicle fault simulation parts.

4.6. Simulation Method of Bus Communication Faults
The bus communication fault phenomenon refers to faults such as communication loss, communication error and bus off when communication between vehicle controllers occurs. The increase in the number of car functions has led to a sharp increase in the number of controllers on the car and various car buses for communication between controllers have emerged. At present, the communication buses used in China VI OBD is proposed for light-duty vehicles mainly include CAN, LIN, FlexRay, SENT, CAN FD and so on.

The simulation method of bus communication fault is to use a bus simulation tool for bus measurement, simulation and analysis. Based on the communication bus description file, the bus simulation tool is used as a communication gateway to bypass the DTC related message and simulate the fault conditions. The message information underneath, thereby triggering a communication type failure. Where, the description file of the CAN bus is a DBC format file, the description file of the LIN bus is a LDF format file, and the FlexRay bus description file is an XML format file. CAN bus simulation can choose CANoe, CANalyzer, Kvaser CanKing, PFautoCAN and other tools. LIN bus simulation can choose CANoe, CANalyzer, linRBS, Emulin and other tools. FlexRay bus simulation can use CANoe, PowerFlex and other tools. SENT bus simulation can choose CANoe, KOPF Tools such as Automotive Interface 4. CAN FD bus simulation can use tools such as CANoe and other tools.

4.7. Simulation Method of Exemption Test Faults
The exemption test failure is a fault that can be applied for an exemption test in the PVE test.
The fault that has been completed in the vehicle OBD demonstration test report does not need to be repeated during the PVE test. It belongs to the PVE exemption test faults. In addition, the safety monitoring fault and the basic software detection fault in the controller need to modify the controller software when performing fault simulation. They do not meet the PVE test requirements and belong to PVE exemption test faults. The chip and its peripheral circuit faults in the controller are in progress. In the fault simulation, the controller hardware circuit needs to be modified, which means damaging the vehicle components and does not meet the PVE test requirements. Therefore, it is also a PVE exemption test fault.

5. Conclusion
The OBD system of light-duty vehicle is the key technology of the vehicle electronic control system. Its fault diagnosis function is being continuously developed and improved, and the monitoring items are constantly increasing and tightening. The domestic research on OBD started late and the PVE test method is not mature enough. The China VI emission regulations of light-duty vehicle have forced the vehicle manufacturers and research institutions to speed up the PVE test and its test method development.

This paper studies the PVE test problem of latest OBD certification in the China VI emission regulations for light vehicles. Firstly, the working principle and development process of OBD system is introduced. Secondly, the PVE testing regulations and testing process of OBD system is analyzed. It covers standardized verification (J1), monitoring requirement verification (J2) and in-use monitoring performance verification (J3). Thirdly, a faults classification method based on fault type and function is proposed. OBD faults can be simplified into the six categories, which include circuit fault, circuit fault, tool performance fault, hardware performance fault, bus communication fault and exemption test fault. The simulation method of corresponding fault is introduced as well. Finally, a PVE test method of China VI OBD is proposed for light-duty vehicles.

References
[1] Timothy Johnson 2014 Vehicular Emissions in Review SAE Paper 2014-01-1491
[2] Fontaras G, Franco V and Dilara P 2014 Development and review of Euro 5 passenger car emission factors based on experimental results over various driving Cycles Science of the Total Environment 468 1034-1042
[3] Ministry of Ecology and Environment 2016 GB 18352.6-2016 Limits and Measurement Methods for Emissions from Light-Duty Vehicles (China 6) China Environmental Science Press pp 326-328
[4] Nanjundaswamy H K, Deussen J and Van Sickle R 2015 OBD Diagnostic Strategies for LEVIII Exhaust Gas Afttreatment Concepts SAE International Journal of Passenger Cars Mechanical Systems 8 37-45
[5] CARB 1997 On Board Diagnostic (OBDII) Final Approved Regulations California Code Regulations Title 13 Sacramento CA California Air Resources Board
[6] Sosnowski and Gardetto E 2001 Performing Onboard Diagnostic System Checks as Part of a Vehicle Inspection and Maintenance Program Environmental Impacts
[7] CARB 2004 Malfunction and Diagnostic System Requirements for 2004 and Subsequent Model-Year Passenger Cars Light-Duty Trucks and Medium-Duty Vehicles and Engines (OBD II) California Code Regulations Title 13 Sacramento CA California Air Resources Board