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Analysis on Factors Affecting Leak Detection of Vehicle Fuel Evaporative System

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Abstract

Many factors could affect the detection of a leak on a vehicle fuel evaporative system. This paper investigates the impacts of orifice diameter, tank ullage volume, initial decay pressure, and hot soak temperature. The leak in the fuel evaporation system of a gasoline vehicle was simulated by using the orifices with standard diameters. The pressure decay method was utilized in orifice diameter, ullage volume, and initial decay pressure experiments. This method utilizes an air compressor to establish a certain pressure for the system, after which the orifice is turned open and the pressure change overtime is recorded. Engine off nature vacuum method was utilized in hot soak experiments. After the hot soak in an aging room, the evaporation system was moved to a lower-temperature environment, then the pressure change was recorded. The results show that the larger the diameter of the orifice, the shorter the pressure decay duration. The pressure decay duration of test bench with a 1 mm orifice is just one-fifth of that with a 0.5 mm orifice, which means that the pressure decay method is suitable for leak detection. The pressure decay duration decreases with the ullage space of tank, so the leak detection is not suitable to be performed when the fuel level is too high nor too low. The ambient temperature has a certain effect on the results, but the absolute error is not significant. The result of leak detection is less affected if the criteria is chosen based on the pressure change characteristics of the first 50 s of pressure decay duration.

Introduction

To reduce or even eliminate the leak of the automotive fuel evaporative emission system, China implemented the Limits and Measurement Methods for Emissions from Light-duty Vehicles (CHINA 6) in July 2020. This regulation mandates the implementation of a diagnostic system capable of detecting leaks in the evaporation systems (EVAP system) of a car equipped with a gasoline engine. According to the regulation, the system must be able to detect the leak with a diameter larger than 1 mm, and the minimum in-use-performance-ratio (IUPR) is 0.26.

Many methods were developed in the past decades. The vacuum decay method (VDM) [1] performed under the engine idle condition was developed. This method uses the engine's intake manifold to establish the vacuum for the evaporative system and measures the change in pressure, and then determines whether the leak exists by the characteristics of the vacuum change. Perry et al. developed the Pressure Decay Method (PDM) [2], which uses an air pump to pressurize the EVAP system and determine whether the system has a leak or a fault by detection the positive pressure decay characteristics in the system. Deronne et al reported the Engine Off Natural Vacuum (EONV) method [1], as indicated by its name, this method runs after the engine is switched off. The diagnose procedure consists of four phases which are the volatility phase, pressure phase, vacuum phase, and analysis phase.

Based on these leak detection methods, some corresponding detection systems have been developed, including a vacuum leak detection system [2], a high flow rate positive pressure method detection system, etc. In terms of system components, Perry [3] and Balsdon [4] respectively developed pressure management devices. The former can ensure that the negative pressure in the EVAP system does not exceed the threshold value during leak detection. The latter ensures that both the positive and negative pressures in the system do not exceed the threshold.

While researching and developing various leak detection systems, Kobayashi established a leak orifice diameter evaluation model using PDM and VDM based on the gas state equation [5]; Cavina established the use of PDM conservation model of gas mass and energy in the fuel tank [6]; Tseng established the relationship between pressure and temperature in a pure vapor space using the EONV method and an optimization model for setting the detection threshold [7]. To ensure the accuracy of these detection systems, Dudar used fuel level sensors, pressure sensors, and temperature sensors of the intake manifold to correct detection errors results from fuel tank deformation [8]. Li verified whether the system has a leak by measuring the differential ratio signal of pressure and temperature, and reduced the decision buffer area for leak detection [9].

The California Air Resources Board (CARB) and Environmental Protection Agency (EPA) standards are getting stricter and stricter, to meet the future standards, Dadam et al. [10] proposed an algorithm needed to detect and diagnose

At 30^{th} second, the pressure decay rates are 0.08, 0.09, and 0.13 kPa/s respectively under the condition of initial decay pressures of 6.5, 8.5, and 10.0 kPa. Besides, when the initial decay pressure is 6.5 kPa, the end time of pressure decay is 63 s advanced than when the initial decay pressure is 8.0 kPa.

According to the ideal gas law, for the same ullage volume, if the initial pressure is smaller, the total mass of the gas pumped into the ullage space of the EVAP system by the air compressor is smaller. Therefore, in the process of pressure decay, the end time of the pressure decay of the system with the lower initial pressure is a little advanced than the system with a higher initial pressure. From the above analysis of the experimental results, it is known that to shorten the time needed for leak detection, the initial decay pressure should be as small as possible.

Conclusion

The factors affecting the EVAP system leakage detection were tested using the PDM and EONV method. The influence of each factor on the leakage detection was analysed by the pressure change in the system.

The statistical analysis results show that the larger the diameter of the orifice, the shorter the duration of pressure decay; the smaller the ullage volume, the shorter the duration of pressure decay; the smaller the initial decay pressure, the shorter the duration of pressure decay; the higher the hot soak temperature, the shorter the pressure decay duration. If leak detection is performed within 1-50 s of pressure decay, the accuracy of leak detection is less affected by the noise factors investigated in this paper.

The EVAP leak detection has to be completed with a relatively high frequency to comply with the regulation, which does not allow isolating all the factors. Apart from the above-discussed factors, other noise factors could also introduce uncertainties to EVAP leak detection. The investigations of those factors are the future works. For example, the fuel volatility is a critical issue especially for the vehicles driven in hot climates, as the pressure change due to the fuel evaporation may lead to underestimated leak. In addition to high temperature, the presence and intensity of fuel slosh also increase the fuel evaporative rate. Besides, it is possible that the temperature rise after engine off may be too low to perform an ENOV test, so it should be investigated with various parking environment during key-off stage. After the leak event has occurred, the method of positioning and the repair of the leak is the future work as well.

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Definitions/Abbreviations

CARB - California Air Resources Board

EONV - Engine off natural vacuum

EPA - Environmental Protection Agency

EVAP - Evaporation system

OBD - On-board diagnostics

IUPR - In-use performance ratio

PDM - Pressure decay method

RVP - Reid vapor pressure

VDM - Vacuum decay method

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