

Effects of Port Injection Specifications on Emission Behavior of THC

Yoshinori Nakao, Yota Sakurai, Atsushi Hisano, Masahito Saitou,
Masahide Kazari, Takahito Murase, and Kozo Suzuki
Kawasaki Heavy Industries, Ltd.

ABSTRACT

In port injection, it is difficult to control in-cylinder fuel supply of each cycle in a transient state as cold start (in this paper, cold start is defined as several cycles from cranking at low engine temperature). Hence, THC, which is one of regulated emission gases, is likely to increase at cold start. As one of THC emission reduction approaches at cold start, the optimization of fuel injection specifications (including injection position and spray diameter) is expected to reduce THC emission. Setting injection position as downstream position is expected to secure the in-cylinder fuel supply amount at cold start because of small fuel adhesion amount on an intake port wall and a short distance between the injection position and in-cylinder. The position injection contributes to reduction of THC emission due to elimination of misfire. Additionally, fuel atomization is also expected to be effective at cold start because mixing promotion caused by fuel atomization is dominant in low engine temperature. On the other hand, the effect of injection specifications under warm-up (in this paper, the engine temperature is relatively lower than hot condition) is also evaluated in this paper. Additionally, the spray behavior in intake port is observed by visualization in intake port. In this paper, fuel atomization method is injection pressure increasing. In comparison with the upstream position injection, downstream position injection improves engine startability and reduces THC emission. Furthermore, the spray diameter at cold start decreases with increases in injection pressure. On the other hand, the fuel adhesion amount on intake valve surface under warm-up becomes less than that at cold start. The THC emission remains approximately the same, regardless of fuel atomization.

CITATION: Nakao, Y., Sakurai, Y., Hisano, A., Saitou, M. et al., "Effects of Port Injection Specifications on Emission Behavior of THC," *SAE Int. J. Engines* 9(4):2016, doi:10.4271/2016-32-0065.

INTRODUCTION

In motorcycles, new European Emission Standards, Euro5 will become effective in 2020. A large amount of the THC, which is one of regulated emission gases, is exhausted from a tail pipe during cold condition (in this paper, cold condition is defined as low engine temperature condition and including cold start). The following are given as the reasons: 1) the catalyst is in an inactive state, 2) combustion deterioration due to low in-cylinder temperature and low engine load, and 3) rich combustion in order to control combustion deterioration etc. Additionally, in emission gas measurement mode (WMTC mode), THC emission that can never be ignored is exhausted during cold condition. General THC emission reduction approaches during cold condition are shown in the reference Kitagawa wrote [1].

Meanwhile, port injection is the mainstream fuel supply system in motorcycles, and it has the following characteristics: 1) long transport distance from the injection position to in-cylinder, and 2) fuel adhesion amount on the intake port wall surface. It is supposed that the above characteristics cause fuel transportation lag until an appropriate fuel amount has been supplied to the in-cylinder at cold start. As previous studies examined port injection spray behavior in

an intake port, Moriyoshi et al had studied on mixture formation process in the port injection of motorcycles and proposed that air velocity and temperature influenced mixture formation [2]. Meanwhile, Kaneko et al had studied that fuel evaporation promotion in an intake port by a tumble generation valve, which enhanced flow velocity in the intake port behind the tumble generation valve, reduced THC emission at cold start [3]. From the above mentioned, it is supposed that THC emission during cold condition also becomes large in port injection (the details for one of the mechanisms are discussed in the next section).

Accordingly, this paper focused on a fuel injection system to specifically examine effects of the injection position and spray diameter on the THC emission at cold start and its mechanism. Furthermore, this paper also discusses THC emission of the same specifications at the time corresponding to that of an engine warm-up time.

THC EMISSION REDUCTION APPROACH AT COLD START

Cold start is one of the main conditions of the sources emitting the THC emission during cold condition. Thus, this paper examines fuel injection systems that have a large effect on the behavior at cold start.

As shown in Figure 1, in the case where the position of the injector is far from the in-cylinder (hereinafter referred to as upstream position injection), it is assumed that the fuel is not supplied sufficiently in the first cycle at cold start. Hence, the position injection causes misfire and increase THC emission. Then, in the second cycle at cold start, it is assumed that the fuel remaining in the intake port due to the fuel adhesion onto the wall surface and the fuel spray, which is injected during previous cycle and do not reach to the in-cylinder during the cycle, is supplied to in-cylinder during current cycle. Thus, the in-cylinder fuel concentration in second cycle becomes rich conversely. As a result, the THC emission increases because of rich combustion. Thus, in the upstream position injection, when the number of cycles is many, in-cylinder A/F becomes stable. However, when the number of cycles is few as the first and second cycle, in-cylinder A/F becomes unstable and THC emission also increases.

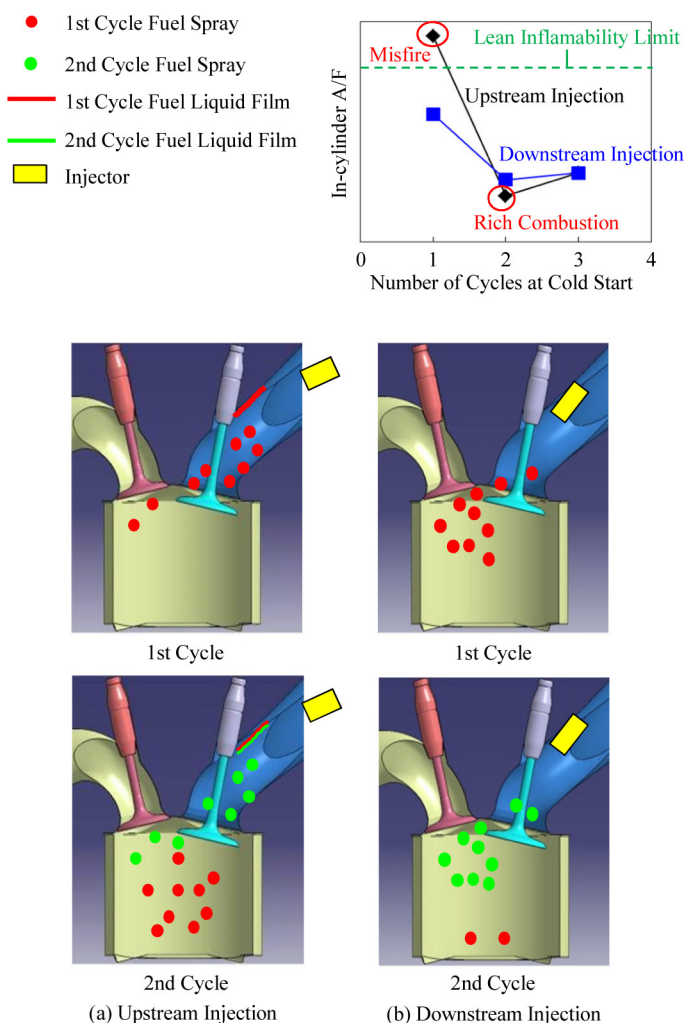


Figure 1. In-Cylinder Fuel Behavior Image at Cold Start

On the other hand, in the case where the injection position is brought closer to the in-cylinder (hereinafter referred to as downstream position injection), it is expected that misfire can be controlled

because of more stabilization of in-cylinder A/F even from the first cycle at cold start and the THC emission can decrease due to control of excessive richness in the second cycle.

Furthermore, it is assumed that fuel evaporation rate is slow at cold start. Hence, especially in downstream position injection, the effect of the fuel spray diameter to combustion is large because the fuel is injected in a state closer to the in-cylinder. Accordingly, it is expected that the effect to reduce the THC emission at cold start by promoting fuel atomization becomes even larger in downstream position injection.

Finally, even in fixed point operations where the load is low during warm-up, this paper examines whether downstream position injection and fuel atomization are effective to reduce the THC emission.

EXPERIMENTAL PROCEDURE

Experimental Apparatus

An intake port visualization apparatus in an engine bench test is shown in Figure 2 and the outline figure of the measurement system is shown in Figure 3. In order to observe the spray behavior, the visualization in the intake port (including the intake valve) is performed by irradiation into the intake port. This is performed by passing a light cable (on which light is transmitted by a xenon light) on the coaxial cable of a bore scope, which has lens at the end face and is installed in the intake port using a high speed camera. The frame rate is 5000 frames/sec. Furthermore, since the change rate of the crank angle speed is extremely large at cold start, the combustion characteristics at cold start are evaluated by the combustion analysis system specialized with respect to the combustion analysis at cold start. With respect to the exhaust gas measurement, direct measurement of the combustion exhaust gas prior to passing a catalyst is performed by exhaust gas analyzer. Additionally, the high speed camera photograph, the injection timing signal, and the crank signal are taken into data logger. Simultaneously, the injection timing signal and the crank signal are also taken into combustion analysis system. Thus, these data are synchronized.

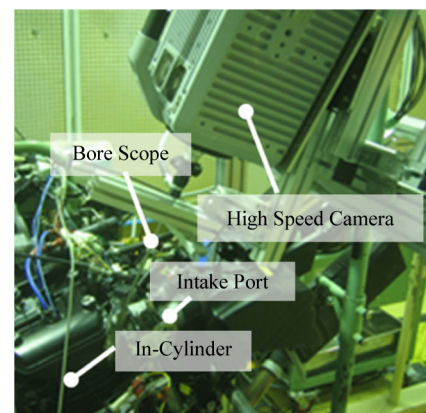


Figure 2. High Speed Photography System

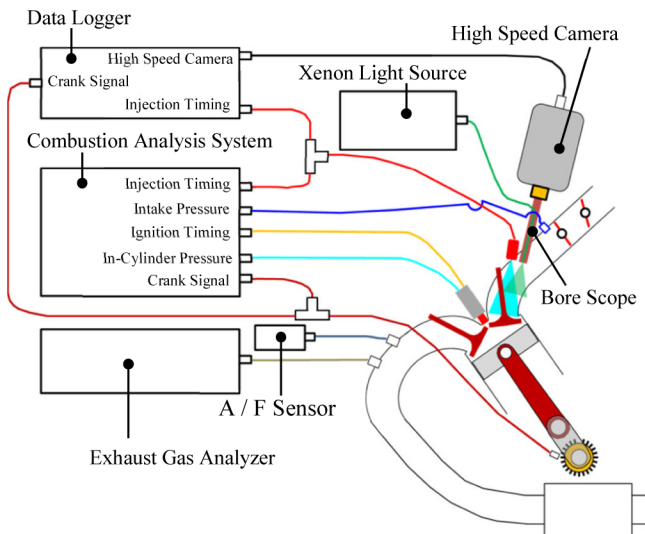


Figure 3. Measurement System

Experimental Specification

The test specifications are shown in Table 1 and the injection positions are shown in Figure 4. Atomization is realized by increasing the injection pressure. In contrast to upstream position injection, the fuel is injected in order to directly aim at the intake valve by downstream position injection, which is laid out such that the fuel adhesion on the wall surface within the intake port is minimized.

Table 1. Test Specification

Test Specification	Injection Position	Injection Pressure [kPa]
upstream_300kPa *	Upstream Position	300
upstream_700kPa	Upstream Position	700
downstream_300kPa	Downstream Position	300
downstream_700kPa	Downstream Position	700

* "upstream_300kPa" is reference test specification

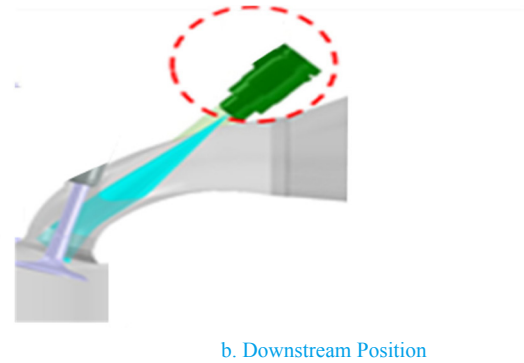


Figure 4. (cont.) Injection Position

Experimental Condition

With respect to the measurement at cold start, the transient measurement is performed for 15 seconds immediately after cold start. In each experimental specification, start crank angle phase and transient fuel and intake mass flows are equal to the maximum extent possible.

Furthermore, in order to evaluate the presence/absence of the effect to reduce the THC emission under warm-up condition by the above mentioned THC emission reduction approach, the measurement at warm-up condition is also performed. Representative fixed operation point of WMTC Part I and the warm-up condition is shown in Table 2.

Table 2. Experimental Condition under Warm-up

Operation Condition	Engine Revolution [rpm]	BMEP [kPa]	Water Temperature [°C]	Exhaust A/F [-]	Ignition Timing [BTDC deg]
Warm-up (Representative Point of WMTC Part I)	2000	110	40	13	Base

FUEL INJECTION BEHAVIOR IN THE INTAKE PORT BY VISUALIZATION

Cold Start

The visualization results of intake port at cold start immediately after the injection are shown in Figure 5. The results indicate that in both the upstream position injection and downstream position injection of Figure 5, the spray diameter becomes smaller as the injection pressure increases and this indicates the promotion of fuel atomization. It is assumed that an increase in the injection pressure promotes fuel atomization because the shearing system between the intake air and fuel spray generates within the intake port. Additionally, with respect to upstream position injection, the findings reveal that the fuel spray amount reaching the intake valve is scarce irrespective of the injection pressure. It is assumed that the fuel adhesion amount on the upstream region wall surface in the upstream position injection is large when compared with that in the downstream position injection.

Next, the visualization results in the intake port at cold start immediately prior to the injection are shown in Figure 6. Incidentally, Figure 5 corresponds to the injection timing that follows the timing in

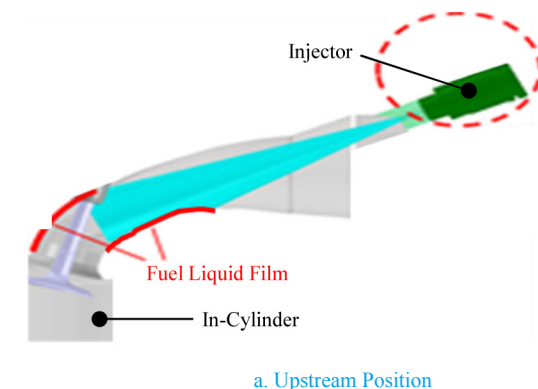


Figure 4.